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U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.
BULLETIN No. 1.

NOTES

ON THE

CLIMATE AND METEOROLOGY

OF

DEATH VALLEY, CALIFORNIA.

BY

MARK W. HARRINGTON,
CHIEF OF WEATHER BUREAU.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., May 24, 1892.

SIR: I have the honor to submit herewith for publication Weather Bureau Bulletin No. 1, Notes on the Climate and Meteorology of Death Valley, California.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

Hon. J. M. RUSK,
Secretary of Agriculture.

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NOTES ON THE CLIMATE OF DEATH VALLEY, CALIFORNIA.

I.—PHYSICAL FEATURES OF THE VALLEY.

The southwestern corner of the arid region of the west is occupied by the Colorado and Mohave deserts, the latter the northern and more extensive of the two. The northern margin of the Mohave Desert reaches out into narrow valleys lying between bold ridges of mountains which run nearly north and south. These valleys are usually shallow, but a few are characterized by great depth. The most remarkable of these is Death Valley, in that its bottom is said to descend below sea-level, while it is about 200 miles from the coast, and between it and the latter intervenes the lofty Sierra Nevada Mountains. This valley is said to owe its name to the melancholy fate of a party of immigrants, who, about 1850, perished from thirst within its limits.

Death Valley lies between the brilliantly colored Funeral and Amargosa ranges of mountains, reaching an elevation of 5,000 to 6,000 feet on the east, and the Panamint Mountains on the west. The latter reach an elevation of 8,000 or 9,000 feet, and culminate opposite the middle of the lower valley in Telescope Peak said to be 10,938 feet high. The valley is an independent drainage basin, nearly closed in on the south by a rapidly-rising ridge about 2,000 feet high. The southern part, into which pours the catch of the entire basin and that of the higher Amargosa Valley on the east, is nearly level, and it is to this portion that the name, Death Valley, is applied. The gradually rising northern or northwestern arm is 50 or more miles in length. It is mapped as "Lost Valley," but is usually known as "Mesquite Valley," under which name the meteorological observer refers to it in his notes. Death Valley proper lies between latitudes 35° 40′ and 36° 35′ north, and longitudes 116° 15′ and 117° 5′ west from Greenwich. It is directly east of Tulare and Owens lakes, about 50 miles from the latter, and the boundary between Nevada and California runs not far east of its eastern margin. It is about 75 miles long, with an axis running nearly north-northwest and south-southeast. The width from crest to crest is from 20 to 25 miles, but the bottom is only 12 or 15 miles wide at its widest point; opposite the meteorological station it was about 6 miles wide.

The first visit to this valley by scientific observers seems to have been made in 1861 by a party of the California and United States Boundary Commission, in charge of Dr. Owen. In the summer and early autumn of 1875 one of Wheeler's surveying parties, under

Lieutenant R. Birnie, jr., crossed it several times and camped some days within it. A brief account of these visits is given in Wheeler's annual report for 1876, pages 132 and 133. Wheeler's surveys were later reduced to a series of "Atlas sheets," on number 65^D of which may be found a map of Death Valley. A copy of the eastern half of this, enlarged by photography to a scale of 4 miles to the inch, was kindly furnished by Mr. Henry Gannett of the Geological Survey.

In 1891 an exploration of the valley was made under the direction of Dr. C. Hart Merriam, with the co-operation of the Geological Survey and the Signal Service, continued by the Weather Bureau. The present paper is the meteorological contribution to the results of this exploration.

A correct interpretation of the meteorological phenomena requires some knowledge of the physical features of the valley. The following notes on this point have been in part gleaned from Birnie's and Wheeler's reports and Cronise's "Natural Wealth of California," and in part from manuscript notes of the meteorological observers in Death Valley and at Keeler. The valley proper is probably the bed of a former lake of bitter water. Along the east side runs a long, narrow, glistening white artery of salt, with borax deposits in three or four places sloping down to it. The crust is usually very thin, breaking through under the feet of the traveler; but in one place it is strong enough to hold up, without breaking, the roadway that crosses it. Some portions of the valley bottom near a salt marsh at the northern end are covered with white, shifting sand, or an ash-like earth mixed with a tenacious clay. When wet it is very soft, and can be traversed only with great difficulty, and only when dry is it possible to cross with horses.

The Amargosa River, a stream of great length but very small volume, comes into the valley at the southern end. It rises in Nevada, and passing through the shallow valley, to which it gives its name, just east of the Funeral range, it flows around the southern end of this range. It is about 100 miles long, but is generally dry in some parts of its course, and is nearly always dry where it enters Death Valley.

Furnace Creek flows into Death Valley near the northeastern angle from a cañon of the Funeral Mountains. Its waters are derived from numerous warm springs that rise on the north side of the cañon, a mile above its mouth. The warmest of these have a temperature of about 90° F. [Birnie]. The cañon is 10 or 15 miles in length, but the stream is only about 2 miles long, and the water sinks before reaching the bottom of the valley. The water is the best for drinking and domestic use, though by no means cool. From the north a stream is said to flow in from Mesquite Valley, which gives a quantity of bitter water.

There are also a few springs along the west side of the valley. In wet seasons there must be much drainage from the mountain slopes and from the valley to the north.

Water is probably often present here on the surface during some seasons and there is no reason why a temporary lake may not exist at times. Such a lake has been occasionally reported, and Birnie found fresh and clean layers of salt with distinct ripple-marks. In dry seasons there is no water on the surface, but it can be found almost anywhere by digging down a few feet. The water appears, however, to be always somewhat unwholesome and it is generally so bitter and saline as to be entirely undrinkable by man or beast.

The salt marsh at the bottom of the valley is destitute of vegetation, but is bordered on the west by numerous clumps of mesquite. It is encircled by a slope a mile or two wide on the east side and 6 to 10 miles on the west side, running up to the mountains, and sparsely covered with several species of desert shrubs and cacti, interspersed with tufts of bunch grass. This slope is crossed by numerous gullies, generally dry. At the northern end of the valley is a salt marsh covered with a tall, coarse grass. The sand is here bare and white, but over it are scattered a few clumps of mesquite, from around which the wind has carried the sand away until they are perched upon hillocks, 15 or 20 feet high [Birnie].

The animal forms noted by the observer, or already recorded, in summer are few. Horned toads, lizards, and snakes are the most conspicuous forms of animal life, while Cronise mentions a small black gnat which, swarming in myriads during the spring, greatly annoys the traveler by entering his eyes, ears, and nose. On September 1 the observer noted a large flock of blackbirds which made their appearance near Furnace Creek.

The valley has been often visited by prospectors who have made prolonged stays there in search of its reputed mineral wealth. One man is reported to have kept cattle on the mountain side for a year or more. About a mile northwest of the mouth of Furnace Creek, on the east side of the valley, is what the Pacific Coast Borax Company, owners of the property, call "Greenland Ranch." About 30 acres are fenced in and water is brought from Furnace Creek for irrigation and stored in two small reservoirs. The plot is very productive, yielding six or seven crops of alfalfa per year. A few cottonwoods and fig trees are grown by aid of constant irrigation. The fruit of the fig tree matures early, and, though small, is of good quality.

The feature of greatest interest about Death Valley is its reputation for extending below sea-level. The observations on which this conclusion is based seem to be all barometric, and have apparently never been published. Lieutenant Birnie says (Report, 1876, p. 132) that his first station in the valley was a few feet below sea-level. This was at Bennetts Wells on the west side. He afterwards found that there was a considerable space in the bottom of the valley which was about 100 feet below sea-level. In Lieutenant Marshall's report on the "Results in Barometric Hypsometry" (Wheeler's Geo. Surveys, Vol. II, p. 558) are given six stations in Death Valley with altitudes of —69.2, +57.1,

+7.3, —45.3, —62.4, —110.0, and —63.9 feet, where the negative sign indicates below, and the positive above, sea-level. These stations are not described in the text, but are given on the map sheet 65^{D}. Williamson, in his book "On the Use of the Barometer in Surveys and Reconnoissances," says (page XXV) that Death Valley is "estimated from reliable barometric observations to be 175 feet below the level of the sea." The exploration of 1891 included work by a topographer, and his results will undoubtedly give greater consistency and exactness to questions of the elevation or depression of the valley. In the meantime it should be noted that barometric observations are an unsatisfactory expedient for determining elevations under the most favorable circumstances. In this case they are rendered still more unsatisfactory by peculiarities of pressure, which will appear later in this paper, due to the physical peculiarities of the valley.

II.—THE STATION AND INSTRUMENTS.

The meteorological station was established on April 30, 1891, and the observations continued without a break until the end of the next September, a period of five months during the hottest part of the year. The station was in a building at the borax works known as "Coleman," owned by the Pacific Coast Borax Company, on the east side of and near the northern end of Death Valley proper; it was situated at the foot of the Funeral Mountains, about two miles northwest of the mouth of Furnace Creek, in approximate latitude 36° 28′ north, longitude 116° 51′ west from Greenwich. The correction for 75th meridian time is 2h. 47m. The soil at the station was a white, shifting sand, destitute of vegetation except for an occasional mesquite bush. The observer in charge was Mr. John H. Clery, who deserves great credit for the success with which he carried on the observations under the most trying circumstances. Mr. R. H. Williams was the assistant, but he succumbed to the heat soon after his arrival and had to return to Keeler for treatment.

The account of the instruments which follows is due to Professor C. F. Marvin, in charge of the instrument room, Weather Bureau.

The instruments furnished to the station were, in most respects, the typical and standard instruments supplied to the regular second order stations of the Bureau, with the addition of a barograph and thermograph.

Owing to the difficulties of transportation to the station, special arrangements were made in several particulars to render the equipment as portable as possible, but at the same time providing everything necessary to a fully equipped station.

The following table gives the complete list of instruments and their elevation, so far as known:

Instruments at Furnace Creek (Death Valley), California.

Instrument.	Maker.	No.	Elevation.
Anemograph, U. S. Weather Bureau pattern—			
Robinson anemometer	J. P. Friez	680	2 feet 7 inches above apex of roof; 22.6 feet above ground.
Anemometer register	Hahl & Co	111	
Barograph	Richard Bros	6661	
Barometer, mercurial	H. J. Green	349	2 feet 6 inches above door sill.
Barometer, aneroid (used in monthly comparative readings only).	P. H. B. Naudet.	13	
Compass			
Rain gauge, standard, 8-inch collector		1344	3 feet above ground.
Shelter, standard pattern			Floor 5 feet above ground.
Thermograph	Richard Bros	8981	
Thermometer—			
Mercurial (dry bulb)	H. J. Green	3426	5 feet 10 inches above ground.
Mercurial (wet bulb)	do	3431	
Maximum	do	2761	6 feet above ground.
Maximum (extra, not used)	do	2762	
Minimum, alcohol	do	2197	6 feet above ground.
Minimum, alcohol (extra, not used)	do	2545	
Whirling psychrometer—			
Small size. Wet bulb thermometer No. 2734 Dry bulb thermometer No. 2758	Schneider Bros.	47	
Special. Wet bulb thermometer No. 3427 Dry bulb thermometer No. 3430	Schneider Bros.	37	
Wind vane, special (see text)			

Fig. 1 shows the general arrangement of the instruments in and about the office, as given by report of the observer.

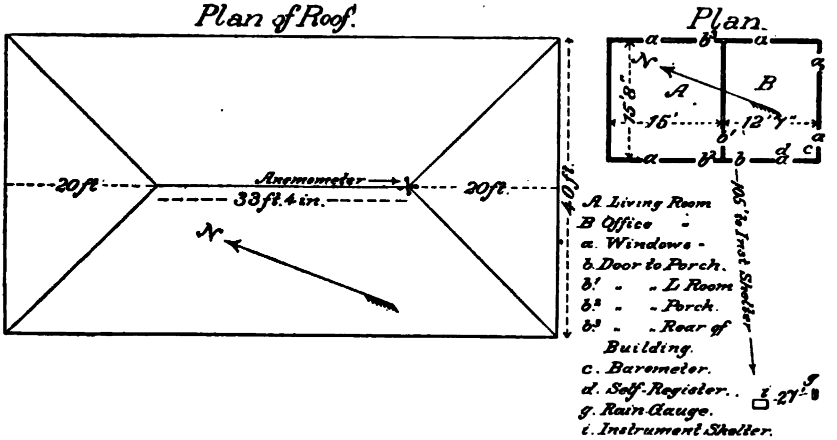

FIG. 1.

A brief discussion of further details respecting the instruments, their errors, etc., is given as follows:

ANEMOGRAPH.

The anemograph is more properly discussed in its separate parts, namely, the anemometer and the anemometer register.

Anemometer.—The anemometer used in measurement of wind movements was of the Robinson type and regular Weather Bureau pattern.

The construction of these instruments is carried to a very high degree of mechanical perfection under the rigid scrutiny of the Bureau, and the observations made at Furnace Creek are considered most satisfactory. The dimensions and important characteristics of the anemometer are repeated here for the convenience of those who may wish to know them.

The four hemispherical cups are each 4 inches in diameter, and are attached to slender, square, steel arms in such a way that the cup centers are each 6.72 inches from the axis of revolution. In accordance with Robinson's original assumption that the travel of the centers of the cups is one-third the wind movement, the above anemometer cups will revolve 500 times per mile of wind, and the ingenious and relatively almost frictionless dial mechanisms are constructed and graduated upon this basis of 500 revolutions to the mile of wind movement.

Provision is made by which the anemometer closes an electric circuit once for each 500 revolutions of the cups; that is, nominally, for each mile of wind movement. This closure of the electric circuit is the means employed to secure the continuous record of the wind movement by means of the anemometer register.

Gibbon's register.—This apparatus consists of a chronograph cylinder whose circumference is just 12 inches and revolved by clock work at the rate of 4 revolutions in 24 hours; that is, 2 inches per hour. In addition to this movement of rotation the cylinder is also made to move endwise about ¼ inch for each revolution. An electro-magnet, the armature of which carries a pencil, is so arranged that the latter may be made to trace a continuous spiral line upon the sheet of paper wound upon the cylinder. When the register is placed in electrical communication with the anemometer, the closure of the circuit in the latter causes the pencil to trace a short mark across the spiral line above described. These cross marks are made for each 500 revolutions of the anemometer cups; that is, nominally, for each mile of wind.

By an ingenious construction of the contact mechanisms in the anemometer one contact in every ten is prolonged during an entire mile of wind movement, making it conspicuous on the record, thereby facilitating the counting of the record and at the same time affording an excellent check against any loss of record from weak batteries and similar contingencies.

From the diagram above it is seen the anemometer was exposed nearly 3 feet above the apex of the roof of the building, at a height of 22.6 feet above the ground.

BAROGRAPH.

The aneroid barograph was of the usual type constructed by the Richard Bros., of Paris. In this instrument eight of the corrugated metallic cells so commonly used in aneroids are joined together so that their united movement with change of pressure acting through properly arranged levers imparts a greatly magnified movement to a delicate recording pen tracing its movement upon the revolving sheet of paper. A pen movement of one inch is thus made to represent a change of one inch in barometric pressure, and the sheet is ruled to spaces of $\frac{1}{20}$ inch; that is, .05 inch of barometric pressure. Owing to the thickness of lines, etc., the error of a pressure reading from the record sheet is, however, probably greater than ±.01 inch. The time movement of the sheet of paper is comparatively slow, being only about 1.6 inches in 24 hours, or about $\frac{1}{15}$ inch per hour. Less than a half hour is, therefore, scarcely discernable, and as the sheet is ruled with lines only for every two hours and as further uncertainty arises from the fact that the clock movements used by Richard Bros. rarely keep very good time, it is impossible to secure very great accuracy from this instrument, even supposing the aneroid mechanisms to be perfectly reliable. As is well known, however, these are never found to keep in close accord with the standard pressure instruments, so that, at best, the barograph is but a differential instrument, whose ever changing corrections for instrumental error must be determined by frequent comparisons with standards. Very similar difficulties arise in the case of the thermograph, and the expedients resorted to in the practice of this Bureau for eliminating errors from these causes will be described further under the thermograph.

It is frequently found that the barographs are but indifferently compensated for temperature, thus giving rise to additional errors. The particular instrument used at Furnace Creek has, however, been carefully tested in this respect and is found to be almost insensible to considerable temperature changes.

BAROMETERS.

Aneroid barometer No. 13.—This instrument was one of the best of its kind, but was furnished only as a last resort in case of failure of the mercurial barometer. Comparative readings were taken between this and the mercurial barometer at the end of each month while the station was in operation.

Mercurial barometer No. 349.—Each regular station is kept supplied always with two good mercurial barometers, but in the present instance only one was furnished, not only because of the temporary character of the station, but as well from the difficulty of safely transporting the instruments from Keeler, Cal., the nearest point of supply.. A newly filled and adjusted barometer was sent out from this office for the station at Furnace Creek, but it did not survive the long journey across the continent, and when examined at Keeler and compared with the station instruments was found to be unserviceable. Instructions providing for such a contingency directed the observer to take the "extra" barometer from Keeler. This barometer was No. 349, a comparatively old instrument, having been in service at Keeler since January, 1885, but in every respect reliable. The scale of this barometer was subdivided to tenths of inches and provided with a vernier reading to .01 inch; estimations to less than .005 being easily made. The barometer tube was approximately ¼ inch in diameter inside, and the construction of the cistern of the regular well-known Fortin type, the mercury in the cistern being adjusted by screw motion to the level of a fixed ivory point.

The correction for instrumental error, including capillary action, was determined by comparison with standards at this office in January, 1885; this correction was +.006 inch.

The temperature of the mercury and scale was taken from the readings of an attached thermometer secured at about the middle point of the tube. This thermometer was not stem-graduated, and the readings could not readily be made to less than whole degrees. When the barometer was returned to this office after the station was closed, a comparison of the attached thermometer with standards showed its corrections to be less than one-half degree, so that possible errors from this source are entirely insignificant.

By a peculiar circumstance of seeming inattention a considerable length of detached thread of mercury remained unnoticed in the top of the attached thermometer, the temperature readings being thereby highly erroneous. This state of affairs was not discovered until the evening of June 15, 1891. During the following day the observer took twenty-five comparative readings, at intervals of one-half hour, with another thermometer suspended near the barometer. The detached column was then united and the next day similar readings were taken, in which the two thermometers gave practically the same temperature. From these comparisons the error of the attached thermometer was found to be a fraction over 26°.

The corresponding error in the barometric pressure was very nearly .07 inch, and instructions were given to correct the back records accordingly, including all records made up from the barograph. The barometer, after over two and one-half years' service at Keeler, was compared in August, 1887, with an inspector's barometer by Lieutenant Maxfield, and found to be in excellent condition, differing by only .002 inch from the readings of his instrument.

Regular monthly comparisons between the two barometers at Keeler showed no deterioration in this instrument. The final series of comparative readings made between the two barometers upon the return of No. 349 to Keeler, after the station at Furnace Creek had been closed, still show No. 349 to have undergone no sensible change in its instrumental error. The comparative readings made during 1891 between barometers No. 349 and No. 509, the station instrument at Keeler, are given in the following table:

Summary of comparison of barometers Nos. 349 and 509, at Keeler, Cal.

Date. 1891.	Corrected means.*		Differences.	Remarks.
	No. 509.	No. 349.		
	Inches.	*Inches.*	*Inch.*	
January 31 ..	26.202	26.203	.001	Made at Keeler before opening station at Furnace Creek.
February 28 .	26.244	26.244	.000	
March 31	26.355	26.356	.001	
April 8	26.409	26.411	.002	
April 10	26.254	26.257	.003	
October 25...	26.512	26.513	.001	After return of instrument from service at Furnace Creek.

* Each of these "Corrected means" is the mean of five readings at intervals of one hour corrected for temperature and instrumental error.

Peculiarly enough, however, this barometer (No. 349) was reported by the observer to be in bad condition and was returned to this office wholly unserviceable; a condition of affairs that seems scarcely possible, except to have been induced by ill treatment after the term of service of the instrument had expired.

In view of these circumstances, therefore, the pressure observations at Furnace Creek can be relied upon as *of as great accuracy as any that we can hope to attain with any single instrument of this type.*

RAIN GAUGE.

The Weather Bureau standard rain gauge is constructed of drawn brass tubing and galvanized iron. The receiving rim, or collector, of the rain gauge is 8 inches in diameter and formed of heavy drawn brass tubing, very accurately sized, and turned to a knife edge around the top edge. The funnel-formed bottom has a slope of 45°, with a hole at the center about $\frac{1}{4}$ inch in diameter. The measuring tube is also drawn brass tubing, very accurately sized to have $\frac{1}{10}$ the area of the 8-inch collector. An outer cylinder of galvanized iron, 8 inches in diameter, surrounds and shelters the measuring tube and supports the funnel-shaped receiver, serving, also, as overflow in case of heavy rainfall. The measuring tube is 20 inches high and, consequently, will contain 2 inches of rainfall. The depth of the water in the measuring tube is determined by the insertion of a carefully graduated cedar stick, divided to inches and tenths. The sectional area of the stick is less than $\frac{1}{100}$ of that of the tube.

SHELTER.

For the exposure of the thermometers, hygrometer, and thermograph, a standard size instrument shelter was furnished, but of special construction to secure lightness and facility in transportation, as well as in the setting up of the shelter at its destination. The interior free space was approximately cubical, nearly 3 feet on a side. The roof was double, with an air space from 6 to 8 inches high, open at the north and south fronts of the shelter.

The louver sides of the shelter were composed of slats nearly 1½ inches from center to center and about 4 inches wide, inclined at an angle of 45°. The floor consists of strips lying close together, and is, therefore, practically continuous, permitting but little or no vertical circulation of air. This shelter was mounted upon wooden posts so that its floor was 5 feet above the ground, and with the sides respectively north and south and east and west. The office building was at a distance of about 105 feet.

THERMOGRAPH.

This recording instrument was also of the Richard Bros. construction, but of somewhat special type in order to more nearly satisfy the requirements of this Bureau than the instruments generally supplied. The temperature scale of this instrument extends from —20° to +110° F., and the cylinder makes two revolutions per week, instead of one as is the general case, thus rendering smaller periods of time perceptible. The clock movement, itself, was also of a superior quality to give better results.

We regret to add that after extended experience with these French instruments and particular efforts at improvement in the clock movements, we find there is still much to be desired, and that serious errors arise from imperfect clock performance, not to mention the thermometric action itself.

The thermometer part of the instrument, as is perhaps quite generally known, consists of a short curved piece of flat metal tubing, having a section shaped much like a very flat ○. Such tubes have the peculiar property of tending to straighten out when subjected to internal pressure, and this is utilized in the present instance to measure temperature by filling the tube with alcohol or similar liquid, the expansion of which with temperature changes gives slight motion to the curved tube, one end of which is fixed while the other, through a system of magnifying levers, communicates motion to a delicate pen tracing its varying positions upon the usual drum of paper. An adjusting screw connected with the fixed end of the thermometer's bulb enables the pen to be set to any particular line on the sheet. By this means the pen could be set low enough on the sheet to take in the very high temperatures at Furnace Creek station. The space on the record sheet corresponding to 1° F. is about .03 of an inch only, and for reasons similar to those given in discussing the barograph, the thermograph also is only a differential instrument and its readings must be constantly corrected for varying instrumental errors.

In transcribing from the record sheets of both thermograph and barograph, observers are directed to apply corrections to the hourly readings of the instruments so as to make the readings at the hours of regular observations agree with the eye readings of the standard instruments. For intermediate hours interpolated corrections are used, which latter are very conveniently determined by aid of a graphical "Correction card," devised at this office some years since, but not heretofore described. A stiff piece of card is ruled and figured as shown in Fig. 2, and small notches cut in two opposite edges at the extremities of one set of lines. A rubber band is stretched across the card and set in notches corresponding to the observed corrections that must be applied to the readings at the 8 o'clock observations. Obviously, the corrections at intermediate hours will be given by the intersection of the rubber band with the particular hour line in question. Moreover, if a real correction is found by observation at any intermediate hour, a pin may be stuck through the card at the proper point, or points, and the band deflected to correspond, as shown in the figure. All the hourly readings taken from the barograph and thermograph traces have been corrected in accordance with these principles.

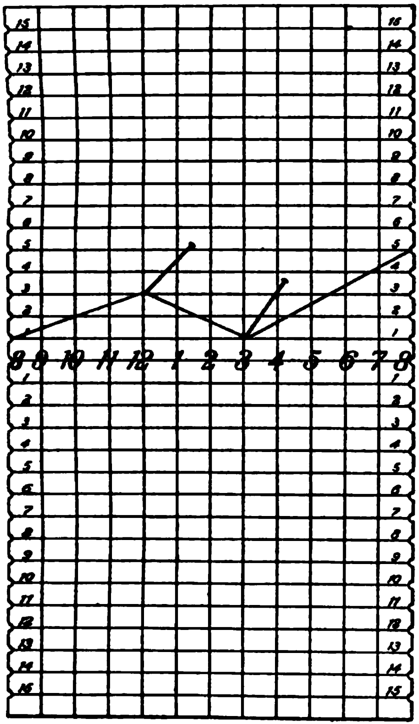

FIG. 2.

THERMOMETERS.

Owing to the extremely high temperatures reported to prevail within the Death Valley region, it was necessary to provide thermometers for higher temperatures than those at regular stations. These were made by H. J. Green, Brooklyn, N. Y., and were unusually nice and all stem-graduated to degrees Fahrenheit. The bulbs of the maximum and minimum thermometers were spherical, about $\frac{3}{8}$ inch in diameter. The remaining thermometers had cylindrical bulbs of between $\frac{1}{8}$ and $\frac{3}{16}$ inch diameter, and from $\frac{1}{2}$ to $\frac{5}{8}$ inch long. With the exception of the "small" psychrometer No. 37 the graduations ranged from 16° to 18° to the inch, rendering tenths of degrees readily perceptible. The corrections to reduce to the standard air thermometer were carefully determined before the instruments were sent out. These corrections, for all the thermometers, are given in the table below.

The exposure of the thermometers within the shelter is described as follows:

Passing east and west across the middle of the shelter inside is fixed a wooden strip about 3 inches wide, to which is secured the maximum and minimum thermometers with their bulbs to the eastern side of the shelter. The wet and dry bulb thermometers, for obtaining air temperature and humidity, are placed to the right of these and toward the western end of the strip.

Corrections to thermometers at Furnace Creek, Cal., September 30, 1891.

Scale reading.	Exposed.		Psychrometers.				Maximum.		Minimum.	
			No. 37.		No. 47.					
	No. 3426.	No. 3431.	Dry. No. 2758.	Wet. No. 2734.	Dry. No. 3430.	Wet. No. 3427.	No. 2761.	No. 2762.	No. 2197.	No. 2545.
°	°	°	°	°	°	°	°	°	°	°
32	0.0	0.0	0.0	0.0	0.0	0.0	−0.1	−0.1	+0.2	+0.4
42	+0.1	0.0	0.0	0.0	0.0	+0.1	−0.1	−0.1	+0.3	+0.6
52	0.0	0.0	+0.1	0.0	−0.1	0.0	+0.1	0.0	0.0	+0.2
62	0.0	0.0	+0.1	+0.1	−0.1	0.0	−0.1	−0.1	+0.1	+0.3
72	0.0	0.0	0.0	0.0	0.0	0.0	−0.2	−0.2	+0.1	+0.3
82	−0.1	−0.1	0.0	0.0	0.0	−0.1	−0.1	−0.1	0.0	+0.3
92	−0.1	+0.1	0.0	0.0	0.0	−0.1	−0.1	−0.1	0.0	+0.2
102	−0.1	−0.1	+0.1	+0.1	−0.2	−0.1	−0.2	−0.1	....	+0.1
112	0.0	−0.1	....	....	+0.1	0.0	−0.2	−0.1	....	+0.1
122	+0.2	−0.1	....	....	−0.2	+0.2	−0.3	−0.2	....	+0.1
132	+0.2	+0.2	....	....	−0.1	+0.3	−0.1	−0.1	....	+0.4
142	−0.1	+0.1	....	....	−0.1	0.0	0.0	0.0	....	+0.6
152	−0.1	+0.3	....	....	−0.1	0.0	−0.1	−0.1	....	+1.0

The thermograph was placed upon the floor of the shelter.

The maximum and minimum thermometers were mounted as shown in the accompanying cut. The wet and dry bulb thermometers, forming the hygrometer, appeared as shown in Fig. 3. In view of the greater accuracy to be secured by the use of the whirled psychrometer, two of these instruments were furnished the observer, and readings were made at each observation.

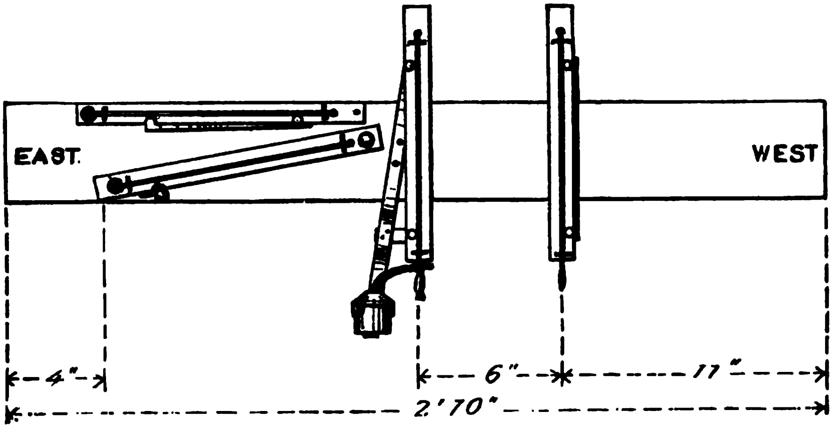

Fig. 8.

A matter of the greatest importance in the construction of the sling psychrometers is that they be exceedingly light, otherwise the arm of the observer becomes very quickly fatigued by a very few observations and the instrument proves a great annoyance. It is frequently written that a sling psychrometer may be easily made by tying the thermometers back to back, or otherwise, and attaching a foot or so of stout cord to a ring or eye at the top of the metal back. Anyone using such a device quickly finds his forefinger seriously rubbed and made sore by the abrasion of the cord. The type of instrument used at Furnace Creek consisted of two thermometers attached side by side to a light strip of aluminium, the wet bulb being considerably below the dry. About 6 inches of light chain of very strong construction is attached to the eye at the top and fitted with a small wooden handle so arranged as to permit of the free movement of the chain in the whirling of the thermometers. A substitute for the chain is often used, consisting of a special swivel and link arrangement that is rather stronger and safer than the chain. This constitutes the standard pattern of whirled psychrometer used by the Weather Bureau, and is shown in Fig. 4. Either form is very light and convenient, and constitutes probably the best simple instrument available for easily securing accurate air temperatures and humidities.

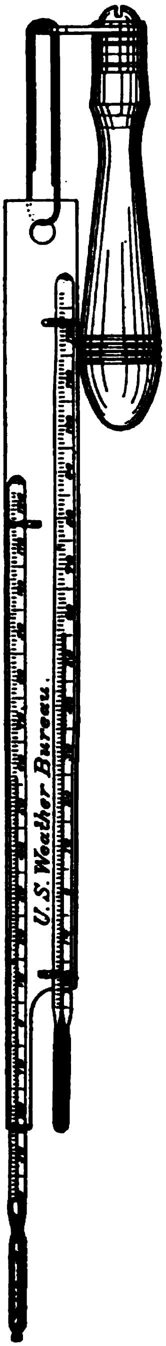

Fig. 4.

On June 5 one of the psychrometers at Furnace Creek was broken because of a defective link in the chain, and still later the wet bulb thermometer of the extra instrument was broken by a falling book while in the office. From this date until the station was closed readings from the stationary psychrometer only were taken.

WIND VANE.

Inasmuch as the direction of the wind is so easily ascertained without the aid of a special instrument none was sent with the equipment for this station, the observer being instructed to display a small streamer or string from some convenient object in a proper locality, and take wind directions accordingly. The point selected by the observer was from a staff attached to the corner of the instrument shelter and at a height of 10 feet above the ground. The north point was located by aid of a small prismatic compass; an allowance of 15° east being made for magnetic variation.

III.—DISCUSSION OF OBSERVATIONS.

The air-pressures obtained by the observations in Death Valley (see Table I at the end) afford several features of interest. The mean pressure for the five months, obtained from the hourly readings, is 29.96 (760.98$^{\text{mm}}$), and this is not reduced for elevation. The average pressure for July is 29.92 inches, or almost exactly 760^{mm}. The July pressures observed in this region, as plotted in Hann's "Atlas der Klimatologie," is 760^{mm}, so that this station is apparently near the level of the sea. The use of the mean monthly pressures compared with simultaneous observations at Yuma, San Diego, Los Angeles, and Keeler, the nearest stations, when used to obtain the elevation of this station, gave very discordant results, varying nearly 300 feet.

The maximum pressure observed was 30.30 on May 22, the minimum 29.41 on September 30. The absolute range for the five months was, therefore, 0.89 inch, a quantity not generally surpassed by other stations in the summer season. The monthly ranges as compared with those of other stations are large, as shown in the accompanying table. They are decidedly larger than those for any station around Death Valley. In general, these ranges are largest in the northeastern part of the United States and decrease as we pass south or west. The ranges in Death Valley approximate those found at Eastport, as shown in the table. The Death Valley monthly ranges are greater than in the greatest part of the United States.

Monthly ranges of barometer, 1891.

Station.	May.	June.	July.	Aug.	Sept.	Average.
	Inch.	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*
Death Valley, Cal	0.71	0.64	0.51	0.49	0.88	0.65
Santa Fé, N. Mex	0.52	0.37	0.32	0.30	0.48	0.40
El Paso, Tex	0.46	0.34	0.36	0.33	0.55	0.41
Fort Grant, Ariz	0.34	0.28	0.27	0.28	0.33	0.30
Yuma, Ariz	0.31	0.31	0.36	0.40	0.54	0.38
San Diego, Cal	0.19	0.21	0.26	0.26	0.39	0.26
Los Angeles, Cal	0.25	0.21	0.26	0.29	0.40	0.28
Keeler, Cal	0.53	0.34	0.36	0.37	0.53	0.43
Fresno, Cal	0.49	0.36	0.45	0.38	0.44	0.42
Sacramento, Cal	0.56	0.34	0.45	0.38	0.45	0.44
Salt Lake City, Utah	0.73	0.46	0.48	0.47	0.55	0.54
Eastport, Me	0.89	0.93	0.72	0.61	1.05	0.84

This peculiarity is to be attributed, in part, at least, to the enormous daily range of pressure in Death Valley. The evening pressures are almost invariably lower than the morning ones. The mean difference for May was 0.19 inch, and for the other months in succession 0.22, 0.22, 0.21, and 0.22. This gives an average of 0.212 inch. Mr. E. G. Johnson, who has assisted me much in getting together the necessary data, compiled the following list to show how this compares with other stations. The data are for 1891, except those for Vienna, which are for 1889, and all are for the same months of the year:

Furnace Creek, Cal., average monthly range	0.212 inch.
Boston, Mass., average monthly range	0.146 inch.
New York City, N. Y., average monthly range	0.129 inch.
Washington, D. C., average monthly range	0.121 inch.
Yuma, Ariz., average monthly range	0.112 inch.
Santa Fé, N. Mex., average monthly range	0.105 inch.
San Diego, Cal., average monthly range	0.066 inch.
Vienna, Austria, average monthly range	0.112 inch.

The mean daily range of the barometer in summer is (as will appear later) very large at Death Valley. This will generally be added to make the monthly maximum, and subtracted in making the monthly minimum, thus increasing the monthly range by approximately twice its amount. Taking this out from the monthly ranges, the Death Valley datum approximates that of Yuma, Ariz., San Diego, Cal., and Santa Fé, N. Mex., and it appears that the pressure in the Valley is submitted to about the same non-periodic changes as that at stations outside, as must, of course, be the case.

The daily temperatures are given in Table II at the end of this bulletin. The absolute maximum was 122° F., and this was reached on several days; three days in succession, on June 30 and July 1 and 2, and again two days in succession in August. This is an excessive maximum, but it has been surpassed in the United States. In July, 1887, at Mammoth Tank, in the Colorado Desert, the temperature reached 128° F. in the shade, and again in July, 1884, it was reported at 126° F. The highest temperature ever reported at any other regular Weather Bureau station was 118°, at Yuma, in 1878. In 1891 the maximum temperatures were the highest ever reported at stations in the interior of the Pacific coast states south of the Columbia River. They were about 110° in the San Joaquin, Sacramento, and lower Colorado valleys in July and August.

The lowest point to which the temperature fell while the station was occupied in Death Valley was 54°, on May 21. Generally the minimum was above 70°, and it not infrequently reached 90°; the highest was 99°, on July 18. A day during which the maximum temperature is 120°, the minimum 99°, and the mean of all hours 108°.6, would not be a comfortable one to pass, yet such a day was passed by the observer in Death Valley on July 18, 1891.

The absolute range of temperature for this period was 68° (54°, 122°). This is not excessively large for so long a period as five months. The greatest daily range was in May, 37°; in June, 44°; in July, 42°; in August, 42°; in September, 41°. These are large, perhaps a half larger than usual over the states, but they can easily be surpassed.

To give some idea of the character of the temperature in Death Valley, as compared with other places in the United States, the following table for July, 1891, may be of service:

Temperatures in the United States, July, 1891.

Stations.	Mean.	Maximum.	Minimum.	Mean maximum.	Mean minimum.	Largest daily range.
	°	°	°	°	°	°
Death Valley, Cal	102.1	122	72	115.6	86.8	42
Yuma, Ariz	92.5	114	64	108.0	76.0	39
Keeler, Cal	81.6	100	57	94.0	69.0	31
Fresno, Cal	83.6	114	51	101.0	66.0	39
San Diego, Cal	69.0	88	58	75.0	63.0	21
Washington, D. C	72.0	89	54	81.0	63.0	29
Chicago, Ill	67.0	87	55	73.0	60.0	22
Rio Grande City, Tex	87.6	105	70	101.0	74.0	29
Mount Washington, N. H	46.0	64	29	52.0	40.0	22

These are all regular stations of the Weather Bureau. Excessive temperatures more nearly approaching those of Death Valley could probably be easily found among the voluntary stations to the south and southeast of this place.

The mean monthly temperatures were 84°.7, 92°.1, 102°.1, 100°.8, 90°.2, for the months in order. For four months the mean temperature was above 90° and for two above 100°. The mean temperature for all five months was 94°. The reputation of the valley for heat is certainly justified.

The period during which the observations were taken includes the hottest part of the year, and it will be interesting to ascertain the time of maximum heat. The records show that the seven days from July 18 to 24, inclusive, was a continuous hot spell, with the highest temperature of any consecutive days of the same number. The minimum did not fall below 88°, and the maxima ran from 119° to 121°. The daily temperature did not fall below 106°.4, and averaged 107°.5. A smooth curve run through the monthly means gives July 24 as the date of annual maximum. This is somewhat later than usual for the Eastern States but not remarkable for the Southwest. It may be a few days later than would be shown by observations for a series of years, as the heat held late in the summer of 1891.

Humidity.—An interesting point in connection with this valley is that of its aridity. It has already been pointed out that water probably stands in the valley occasionally, but this would not happen in the dry season, and the months of observation fall in this season. The average amount of moisture is remarkably constant through the months, as is shown by the uniformity of the dew-points, and consequently that of the weights of vapor in the air. It is also fairly the same at the morning and evening observations. We may conclude that during the months the average quantity of vapor does not vary much in this independent basin in the midst of an arid region and cut off by high mountains east and west. There is a slight deficiency of 0.28 grain per cubic foot at the evening observations as compared with those of the morning, but it is probably due to the rising currents of air during the hottest parts of the day.

Mean dew-points and absolute humidities in Death Valley.

	Dew-point.		Water in grains Troy, per cu. ft.		Mean temperatures.	
	5.13 a.m.	5.13 p.m.	5.13 a.m.	5.13 p.m.	5.13 a.m.	5.13 p.m.
	°	°			°	°
May	41	40	2.97	2.86	73	94
June	42	42	3.08	3.08	81	102
July	49	48	3.95	3.81	89	112
August	48	46	3.81	3.55	87	111
September	47	48	3.68	3.81	79	98
Average	45	45	3.70	3.42	82	103

Dew could not form in the valley under the conditions observed. The maximum approach to dew was on the morning of August 17. The dew-point was then 70°, but the temperature was 79°. There was present only 75 per cent. of the moisture necessary to form dew, but if the temperature had fallen only 9° dew would have begun. The least approach to dew was at the evening observation on August 4. The dew-point was then 22° and the actual temperature in the shade was 112°. There was present only 5 per cent. of the moisture needed to have dew form, and the temperature would have to fall 90° to make it possible. The average dew-point for the whole period (observations twice daily) was 45°, but the mean temperature for the same hours was 93°. The moisture would have to be quintupled or the mean temperature fall 48° lower to make dew possible under these conditions.

But the most interesting form of humidity by which to judge of the comfort to be found in residence at a place, and the animal and plant forms which will thrive in it, is the relative humidity. This is given twice for each day in Table III. The lowest recorded relative humidity in Death Valley was 5 per cent. on the afternoons of August 4 and 5. This was part of a long dry spell. From July 30 to August 9 the relative humidity did not go above 13 per cent. at the afternoon observation, and averaged 8. The highest observed was 75 per cent. on the morning of August 17. The morning observations here were at 5 hrs. 13 min., or about the time of the diurnal maximum of relative humidity, while the evening observations fell shortly after the usual minimum. The observed humidities at these hours are therefore the approximate diurnal maxima and minima, and this gives the accompanying abstract from Table III an interest it would not otherwise have.

Relative humidities in Death Valley.

1891.	Morning.	Evening.
	Per cent.	*Per cent.*
May	34.5	17.8
June	27.2	14.2
July	27.4	12.6
August	29.0	13.0
September	34.2	20.3
Average	30.5	15.6

The difference between morning and evening is due to the difference in temperature for the most part, as it has been already shown that the average moisture is nearly constant. It appears that in the morning the air contains less than one-third the amount of saturation and in the evening less than one-sixth. This will be most instructive if we compare the humidities in Death Valley with other places in the United States. This is given in the tabular statement accompanying, and includes the driest stations, those nearest to Death Valley, the dampest regular station for this season (Fort Canby, near the mouth of the Columbia), and Chicago and Washington for comparison. The record for Fort Grant, Ariz., is not complete, as this station was abandoned in August. It appears to stand next in aridity to Death Valley. At Winnemucca, in August, the dryness was greater than in Death Valley. The aridity of Death Valley can be best judged by comparing it with the relative humidity at Chicago, 72 per cent.; Washington, 77 per cent., and Fort Canby, 96 per cent. Its reputation for aridity in summer seems fully justified, for the low relative humidity (with the large air-motions to be mentioned) would cause evaporation to proceed with very great rapidity.

Relative humidities in the United States, 1891.

Stations.	May.	June.	July.	August.	September.	Average.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Death Valley, Cal	26	21	20	21	27	23
Fort Grant, Ariz	32	26	33	....	....	....
El Paso, Tex	35	26	31	36	40	34
Winnemucca, Nev	49	42	27	18	36	34
Keeler, Cal	38	31	31	35	38	35
Fresno, Cal	52	42	30	31	41	39
Yuma, Ariz	39	37	36	47	40	40
Santa Fé, N. Mex	62	47	44	42	56	50
Sacramento, Cal	74	60	56	59	56	61
Chicago, Ill	67	81	70	74	66	72
Los Angeles, Cal	78	73	73	75	69	74
San Diego, Cal	75	75	78	78	77	77
Washington, D. C	68	74	77	82	83	77
Fort Canby, Wash	92	97	97	96	97	96

The cloudiness was slight (Table IV). In May there were 12 clear days and 14, 15, 17, and 12 in the other months in succession. This makes 70 clear days in 153, or 46 per cent. of days without clouds. In the latter part of July and early in August there were 12 clear days in succession. Only 4 of the 153 days were entirely overcast. The average percentage of cloudiness for five months was 30. This is decidedly greater than for stations around Death Valley, Cal., with very similar physical conditions. Pioche, Nev., had 25 per cent.; Prescott, Ariz., 23; Yuma, Ariz., 14; Visalia, Cal., 14; and Keeler, Cal., 10 for the same period. The greater cloudiness of Death Valley is due to the local storms for which the surroundings of the valley are especially favorable.

There was an appreciable difference in the cloudiness of the morning and evening. For the morning it was 24, 18, 29, 15, and 10 per cent., for the months in order; for the evening observations, 39, 27, 28, 23, and 30 per cent. The general average for the morning was 19 per cent.; for the evening, 29 per cent., or one-half greater.

Cirrus and cumulus types of clouds were about equally common, generally cirro-stratus and cumulo-stratus. This means that the clouds were about equally of general and local origin. Light haze was reported but twice, dense haze but once. The direction of motion of clouds was quite various, but the prevailing directions were, for the months in succession, south, west, southwest, west, and south. The westerly direction was the prevailing one in summer.

The *rainfall* was extremely light. The showers at the station at Furnace Creek are given in the accompanying table:

Rains and accompanying phenomena at the station.

1891.	Beginning.			Rainfall.		Fall of temperature.	Rise of barometer.	Change of wind.	Notes.
	Time.	Temperature.	Humidity.	Duration.	Amount.				
		°	*Pr. ct.*	*h. m.*	*Inches.*	°	*Inches*		
May 21...	2.33 a. m.....	64.5	48	3 10	0.14	9.3	......	....	
Do ..	10.28 a. m.....	68.2	44	0 05	trace.	......	......	none......	Light showers.
Do ..	11.18 a. m.....	72.3	41	0 10	trace.	......	......	none......	Do.
Do ..	5.28 p. m.....	75.0	40	2 55	trace.	......	......	....	Do.
May 24...	3.25 p. m.....	92.3	18	0 05	trace.	4.8	0.03	none......	
May 31...	During night .	......	......	......	0.04	......	......	....	Very light sprinkle.
June 3...	4.53 a. m.....	88.3	28	0 44	0.05	1.3	0.03	....	Light showers.
Do ..	1.23 p. m.....	92.0	22	0 18		1.0	......	....	Do.
June 13..	3.33 p. m.....	86.0	22	0 08	trace.	3.0	0.05	s. to ne ...	Thunderstorm.
July 22 ..	4.56 a. m.....	99.1	8	0 07	trace.	2.6	......	....	Light sprinkle.
Do ..	9.18 a. m.....	108.3	8	0 02	trace.	0.5	......	....	Do.
July 24 ..	10.58 p. m.....	106.6	14	0 25	trace.	14.9	0.19	sw. to se..	Thunderstorm.
July 25 ..	8.13 p. m.....	112.0	11	2 15	0.09	18.5	0.58	nw. to e ..	Do.
July 26 ..	10.13 p. m.....	98.0	15	1 45	0.04	7.5	0.13	none......	Tornadic wind.
July 27 ..	6.30 p. m.....	106.8	11	......	0.24	19.9	......	s. to e	Thunderstorm.
Aug. 16 ..	2.23 a. m.....	92.2	18	2 20	0.54	14.2	0.10	ne. to se..	Do.
Do ..	8.43 p. m.....	98.1	18	3 15	0.06	14.6	0.30	....	Do.
Sept. 5...	12.13 a. m.....	100.8	28	1 12	0.04	4.9	0.08	ne. to w ..	Do.
Do ..	3.43 p. m.....	107.0	29	1 10	0.08	17.5	0.24	n. to ne...	Do.
Do ..	7.43 p. m.....	87.5	54	0 15	0.06	4.0	0.12	none......	
Sept. 6...	7.33 p. m.....	84.5	63	0 15	trace.	......	0.03	....	
Do ..	9.58 p. m.....	92.4	50	0 40	0.02	5.8	0.05	....	

There were 22 showers at Furnace Creek during the 5 months it was occupied as a station. The observer also recorded 9 other cases in which rain was seen to fall on the mountains or there was evidence of a thunderstorm within sight. Of the 22 cases of rainfall at the station, only 13 gave more than a trace, or measurable amount, of rain. These 13 showers fell on 9 different days, and this gives the probability of rain on any day at 9÷153, or 0.06. This is larger than for the stations around Death Valley for the same months; at Yuma the average probability is 0.01; at San Diego, 0.04; at Keeler, 0.04; at Frisco, 0.12; at Prescott, 0.19.

The total rain in the months is, for May, 0.18 inch; for June, 0.05; for July, 0.37; for August, 0.60; for September, 0.20. For the entire period of 5 months the rainfall was 1.40 inches. This, for the dry season, is by no means very dry, but the excessively low humidity and brisk winds evaporate the rain rapidly.

The last column in the table of rainfall shows the character of the rain very distinctly. The rain was always either a slight sprinkle or a thunderstorm, and was, therefore, local in character. There was no general or "blanket" rain during the occupancy of the valley by the observer.

An additional feature is brought out by the columns of temperature and humidity which have been added, and this is of interest in its bearings on rains in arid regions generally. The observations of the wet-bulb thermometer, from which the humidity is deduced, were taken only at 8 a. m. and 8 p. m., hence the humidity cannot be given directly for the intermediate hours, but the hours of observation were near enough generally to permit the following conclusion: *The lower, or surface, air was at no time at or near saturation at the time of rainfall.* During the rainfall in the morning of May 21 the lower air had only 62 per cent. of the moisture of saturation, and during the morning of June 3 only 48 per cent. The nearest hour of observation on July 22 (only 10 minutes after the rain) gave only 20 per cent., and correspondingly with the others. But it will be more interesting to estimate the relative humidity at the time of the beginning of each shower, and this we can easily do by interpolation of the dew-point at the hours of observation. It has been already pointed out that the mean absolute humidity, and hence the mean dew-point, is curiously constant. An inspection of the sheets of observations shows that the dew-point actually changes but slowly and is not infrequently the same in successive observations. Deducing the relative humidity in this way, column six is obtained, and the interesting fact appears that at the beginning of the rains the relative humidity was never greater than two-thirds, was sometimes as low as one-twelfth, and averaged 28 per cent. In the very heaviest rain it was only 18 and it was 63 in one of the lightest—so light that the amount of rain that reached the ground was not measurable. It is a common phenomenon in arid regions, and not unknown elsewhere, to see rain fall from the clouds and fail to reach the ground. At such times the condition of the air at the height of the clouds, where there must be saturation, is very different from that at the surface. At Furnace Creek the superheated air near the ground was apparently a relatively thin layer, so thin that rain-drops formed above could pass through it without entire evaporation notwithstanding its great heat and low humidity. On August 16 over half an inch passed through it, though its relative humidity was only 18 per cent.

It is to be noted, also, that the rain showed a distinct diurnal frequency. Nearly all of the hours of rain were in the night; out of 50 hours of rain 35 occurred from 7 p. m. (local time) to 5 a. m., or from sunset to sunrise. There were only 15 in the hours when the sun was above the horizon. The hours of rainfall during the night were pretty evenly distributed after 8 p. m. (local time).

The winter rains for this place have not been recorded, but as in summer its cloudiness and rainfall compare very favorably with stations about it there is every probability that it has at least the rainfall belonging to its geographical position, with possibly some addition due to the favorable character of the topography for summer rains. To ascertain what this is, the following records are extracted from Lieutenant Glassford's "Irrigation and Water Storage in the Arid Region:"

Rainfall at stations near Death Valley.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
	Inch.	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Yrs.*
Keeler, Cal	0.28	0.38	0.26	0.41	0.31	0.16	0.14	0.08	0.20	0.28	0.41	0.49	3.40	6.2
Camp Independence, Cal	1.22	0.56	0.52	0.21	0.27	0.04	0.11	0.22	0.07	0.32	0.21	2.26	6.01	11.7
Bishop Creek, Cal	1.19	0.50	0.52	0.17	0.12	0.10	0.03	0.00	0.02	0.03	0.35	0.61	3.64	6.7
Camp Cady, Cal	0.18	0.50	0.37	0.25	0.06	0.00	0.34	0.63	0.00	0.30	0.27	0.16	3.08	2+
Barstow, Cal	0.25	0.10	0.46	0.04	0.06	0.00	0.00	0.13	0.07	0.23	0.70	3.87	5.91	1.6
Daggett, Cal	0.48	1.44	1.17	0.10	0.49	0.00	0.00	0.03	0.00	0.00	0.00	0.29	4.00	1.1
Fenner, Cal	0.15	1.30	1.25	0.15	1.09	0.05	0.00	0.00	0.03	0.00	0.00	2.40	6.42	1.2
Needles, Cal	1.68	0.64	1.14	0.10	0.75	0.00	0.04	0.64	0.06	0.12	0.00	2.20	7.37	1+
El Dorado Cañon, Nev	0.64	0.28	0.59	0.15	0.01	T.	1.19	0.61	0.38	0.47	0.54	3.70	8.56	2.7
Yuma, Ariz	0.31	0.39	0.14	0.07	0.00	0.00	0.33	0.66	0.58	0.09	0.30	0.29	3.16	28.0

The second and third stations in this table are in higher latitudes than Death Valley, the others in lower. Camp Cady and the three following are in the Mohave Desert; the last three are on the Colorado River.

For the months covered by the Death Valley records Keeler has 0.89 inch of rainfall; Camp Independence, 0.71; Bishop Creek, 0.27; Camp Cady, 1.05; Barstow, 0.26; Daggett, 0.52; Fenner, 1.17; Needles, 1.49; El Dorado Cañon, 2.19; Yuma, 1.57.

All the stations off the Colorado River give less rainfall in summer than Death Valley, 1.40. The mean of the two nearest, Keeler and Camp Cady, gives a summer rainfall of 0.97 inch, and an annual of 3.24. If Death Valley winter rainfall is as much larger in proportion as is the summer rainfall, this would give it an annual amount of 4.50 inches. Lieutenant Glassford passes his isohyetal of five inches nearly over it, and we may assume, with probability of close approximation, that the annual rain in Death Valley is at least 4 or 5 inches. This is not heavy, but it is heavier than in the desert to the south, as the topography would lead us to expect.

Winds.—Table V gives the direction of the wind at each observation for each day of the five months, and the mean of the velocities of all the hours of the day. Compilation shows that the average frequencies for each month are as follows:

Monthly frequency of wind in Death Valley, Cal.

Direction of wind.	By months.						Average for morning.	Average for evening.
	May.	June.	July.	August.	September.	Average.		
North	6	6	4	0	11	5.4	8.0	2.8
Northeast	3	5	2	2	5	2.4	5.2	1.6
East	4	2	0	3	1	2.0	3.6	0.4
Southeast	29	13	12	10	4	13.6	19.2	8.0
South	16	13	34	32	34	25.8	16.8	34.8
Southwest	1	11	5	6	2	5.0	2.0	8.0
West	1	2	1	4	0	1.6	1.6	1.6
Northwest	1	8	4	2	3	3.6	3.2	4.0
Calm	1	0	0	3	0	0.8	1.6	0.0

It appears that the "sluggish atmosphere" to which writers are fond of referring when describing Death Valley exists only in their imagination, at least in summer. The calms observed in five months in bi-daily observations were only four, and these were all in the morning hour about the time of minimum velocity of wind. From the 306 observations there result only 4÷306, or one per cent. of calms. Yuma, Ariz., in these months in 1889 had 9 per cent.; Keeler, Cal., 10; San Diego, Cal., 16; and Los Angeles, Cal., 28. But records on this point vary much with the station. San Antonio, Tex., in these months had no calms, while Roseburgh, Oregon, had 30 per cent.

The prevailing wind was from the south, nearly one-half of all being from that direction. The north winds were only one-fifth as frequent, notwithstanding the valley lies nearly north and south. The prevailing wind at Keeler was also from the south, but at other stations near this the south wind is not so common—though there is some evidence of a summer monsoon over southeastern California, and this would give generally southerly winds.

The relation of the direction of the wind to questions of temperature and speed also deserves attention. In the accompanying table is given the average temperature and speed of the winds from each point of the compass and also the per cent. of frequency of the highest wind velocity from each point of the compass.

Relations of direction to temperature and velocity.

Direction of wind.	Average temperature.	Average velocity.	Frequency of daily maximum velocity.
	°	*Miles.*	*Per cent.*
North	83	6.0	6
Northeast	80	6.6	6
East	79	8.2	2
Southeast	86	7.2	15
South	98	12.6	55
Southwest	102	10.1	8
West	97	4.0	3
Northwest	90	5.8	5

It will be seen that the winds from down the valley are notably hottest, those from across the valley next, and those from up the valley and from the mountains east follow in order. The winds from down the valley are also those of highest velocity, and also those giving the most frequent maximum velocities.

There is also some evidence of the diurnal change of wind, as appears in the last two columns of the table on page 27 (where the numbers are doubled to make them comparable with the preceding column). This feature is better shown in the accompanying wind roses, Fig. 5. The south winds are more than twice as frequent in the evening as in the morning, and the north winds less than half as frequent. This is a natural result of the heating and cooling of the higher valley to the north.

The mean hourly wind velocities are not materially different from those at other stations. On August 5 they averaged 25.9 miles, but on September 7 only 2.3 miles. The average of all the months was 9.8 miles. The average at Phœnix, Ariz., is only 2.4 miles for the same period; at San Diego, 5.9; at Yuma and Santa Fé, 6.1; and at San Francisco, 11.1. On the whole, the velocity in Death Valley is greater than at neighboring stations.

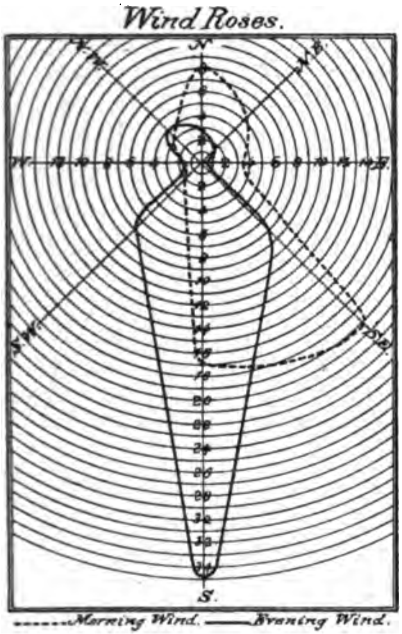

Fig. 5.

Before leaving this part of the discussion it will be interesting to see if such a climate can be equaled in other parts of the earth. The climate of Death Valley in summer is very hot and very dry; at the same time the weather is more cloudy than would be expected; there are some rains, and the winds are fairly active.

If the hottest month of the year is taken (usually July for the northern hemisphere and January for the southern) the regions of excessive heat will be found to be—

The central Sahara with a mean temperature in July of 97° and upwards;

Interior Arabia and westward to the Indus, temperature of July 94° and upwards;

Southern California to Sinaloa, temperature of July 94° and upwards;

Central Australia, temperature of January 94° and upwards.

The center of greatest heat in India migrates a little on account of the summer rains. In May it is central in the peninsula, and the mean temperature is 95° and upwards. In July the temperatures are reduced.

In general these places are in latitudes 20° to 40°, and they are all very dry—generally sandy deserts. Death Valley is in one of these areas, but its topography and soil are especially adapted for producing very high temperatures. To show the character of these differences, four stations in the valley of the Indus and one in the Tunisian Sahara have been selected as marked by especial heat and dryness—the most extreme found where regular observations are taken. The places selected are—

Gardaia, a small irrigated oasis, filled with orchards, in the Tunisian

Sahara, about 175 miles southwest of the Gulf of Gabes, population 12,000;

Hyderabad, a city of 35,000 inhabitants on the Indus, and Jacobabad, 5,000 inhabitants, near the Belochee frontier, both in upper Sinde;

Mooltan, a city of 69,000 inhabitants, formerly much more populous, and Dera Ismail Khan, 12,000 inhabitants, both in the Punjaub.

All these places are celebrated for their great dryness and excessively hot summers.

Comparison of Death Valley and other stations.

Stations.	Month of greatest heat.	Mean temperature.	Absolute maximum.	Mean maximum.	Mean minimum.	Mean daily range.	Relative humidity.	Cloudiness.	Rainfall.	No. of rainy days.	Elevation.	Years of observation.
		°	°	°	°	°	%		*Inch.*		*Ft.*	
Death Valley, Cal	July ..	102.1	122.0	115.6	86.8	29	20	31	0.13	0.37	.....	1891
Sinde:												
Hyderabad..................	May ..	91.0	121.0	106.0	78.0	28	45	7	0.10	1.00	94	8
Jacobabad	June..	96.0	122.2	111.0	83.0	28	42	11	0.10	1.00	186	9
Punjaub:												
Dera Ismail Kahn..........	June..	93.0	121.5	107.0	80.0	27	44	16	0.60	2.00	573	11
Mooltan......................	June..	94.0	118.4	107.0	82.0	25	51	10	0.40	2.00	420	11
Tunisian Sahara, lat. 32° 35′												
Gardaia......................	July ..	96.0	118.4	111.0	78.0	29	25	7	0.08	1.00	706?	1887

It will be seen that Death Valley is both much hotter and much drier than any of these places. It is not that its maximum is so much greater or the diurnal range more severe, but it is more consistently hot than the others. In the others can probably be seen about the best that the sun and drought can do unaided; in Death Valley these are aided by the peculiar topography, and the difference is very appreciable.

It may be of interest to note that the highest maximum observed in the meteorological service of India* was 123°.1, at Pachpadra in Rajputana on May 25, 1886, the same day as the record of maximum at Jacobabad.

A good measure of the rigor of a climate is to be found in the mean daily range of temperature. Where it is small the climate may be hot or cold, but can be endured with much less danger than where this range is large. To ascertain the position of Death Valley in this regard its mean daily range for the months is tabulated with those of other places which can be characterized as of a mild or rigorous climate.

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* Blandford, "Climates and Weather of India," 1889, p. 133.

Mean daily ranges of temperature.

Stations.	May.	June.	July.	Aug.	Sept.	Average.
	°	°	°	°	°	°
Galveston, Tex. [1]	6.8	6.4	6.6	6.5	6.3	6.5
San Diego, Cal. [1]	9.8	9.4	9.5	9.9	10.5	9.8
San Francisco, Cal. [1]	9.4	9.5	10.5	10.4	10.3	10.0
New York City, N. Y. [1]	11.2	11.5	11.0	10.2	10.0	10.8
Washington, D. C. [1]	15.2	14.7	14.4	14.8	14.8	14.8
Santa Fé, N. Mex. [1]	21.6	22.0	20.2	18.2	21.4	20.7
Death Valley, Cal. [3]	21.9	23.3	24.6	27.1	22.2	23.6
Yuma, Ariz. [1]	27.6	28.3	24.0	24.2	24.8	25.8
Winnemucca, Nev. [1]	25.1	25.8	29.3	33.8	31.2	29.0
Hyderabad, India [2]	28.0	22.0	19.0	17.0	20.0	20.8
Jacobabad, India [2]	32.0	28.0	24.0	22.0	25.0	26.2
Mooltan, India [2]	28.0	25.0	20.0	18.0	22.0	22.6
Dera Ismail Khan, India [2]	27.0	27.0	21.0	20.0	25.5	24.0
Leh, India [2]	27.0	30.0	29.0	30.0	30.0	29.2

[1] Taken from Greely's "Mean Temperatures and their Corrections in the United States," 1891, pp. III and IV.

[2] Taken from Blandford's "Climates and Weather of India," 1889, pp. 291, 302, and 303.

[3] From Table VII at the end of this bulletin.

Leh is in Eastern Cashmere in the Himalayas, at a height of 11,503 feet. Comparison shows that while the diurnal ranges of temperature are great in Death Valley, they are equaled and surpassed elsewhere.

IV.—THE WEATHER IN THE VALLEY.

The succession of pentad or five-day means (Table VI) gives an easy bird's-eye view of the progress of the elements in the valley. The novel feature which is brought to light is that the pressure is not in this case the key to the conditions of the weather. As it happens the hottest period (July 15 to 24, when the mean temperature was 106°.7) was the time of nearer mean than low barometer, and the same is true of the next hottest term, August 19 to September 2, when the mean temperature was 103°.1. The coolest period was when the barometer was again about mean (May 31 to June 4, temperature 79°.3). In the same way the wind velocities show no relation to the changes of the barometer. Rain came generally with a high barometer, and the humidity is sensitive to nothing but the rain, so that we have the paradox of greatest relative humidity with maximum pressure.

It will now be interesting to follow the note-books of the observer through his five months' task, noting the phenomena of interest.

Rain storms.—May 13, heavy masses of cumulo-stratus clouds moved rapidly from the south all day. A thunderstorm passed up the valley, seeming to draw from the Panamint to the Funeral range. Rain fell on both ranges, but none in the valley. The thunder was first heard at 2.33 p. m., last at 5.33 p. m. The temperature fell 9°. The wind had been in the south, but at 5.43 it changed to the north and increased gradually in violence until at 7.48 it reached a velocity of 37 miles per hour. This is the familiar summer or heat thunderstorm, common in mountainous regions in hot weather. Similar storms were described on June 13, July 25 and 27, and August 16. All caused a change of wind and fall of barometer. They were always late afternoon or early morning phenomena. Distant thunder and lightning were often recorded when no thunderstorm was seen from the station, and such storms when they came did not always bring rain to the station.

The thunderstorm of July 25 presented some features of especial interest. In the afternoon large masses of thunderheads were seen moving from the southwest and west until darkness set in. The lightning was very vivid, and rain fell to the depth of .04 of an inch. The wind changed from northwest to east, and the temperature fell from 110° to 92°. With this storm came on suddenly a violent wind which unroofed a small adobe building near the station. The roof was thrown about 15 yards westward, and the boards and shingles scattered to the north and west of it. This was apparently a regular whirl, as the wind was previously from the northwest.

The thunderstorm of August 16 gave the heaviest rain of all (0.54 inch). It was a morning thunderstorm, following several days of distant thunder and threatening weather, and it continued only two hours (from 2 to 4 a. m.). The most of the rain (0.51 inch) fell within half an hour. The rainfall on the west side of the valley must have been much larger, as the sound of the water was distinctly heard as it rushed down the cañons six miles distant. Large streams of water also came down on the east side, but no damage was done. The ground became exceedingly soft about the station, and traveling was made dangerous.

The thunderstorm of July 27 caused a fall of 20° in temperature, from 107° to 87°. The rainfall was slight, but the drops were very large and very cold.

Another source of rain was that of the slight showers which occurred on May 31, June 3, and other days. No mention of thunder or lightning is made, and the showers were scattered. The clouds were cumulo-stratus. These are the light cumulus showers of summer.

In all cases the rain was from local storms. There is no evidence of rain from a general storm, and indeed such rain is improbable in this part of the world at this season of the year.

Sand storms were observed several times. On June 29, at 6 p. m., after light westerly winds all day, such a storm came down from Mesquite Valley and passed southward on the west side of Death Valley. The mountains on the west side were entirely obscured, while a dead calm prevailed at the station on the east side until 7.30 p. m., when a high wind set in from the west. Another appeared at 7 p. m. on July 28 and took the same course. It disappeared at 8 p. m., but a thunderstorm was heard and lightning seen to the south until after midnight. Sand storms of the same character were reported on September 22 and 30.

On August 13 the observer had a sand storm at his own station, that is, on the east side of the valley, the preceding having been on the west side. The wind blew a gale, beginning at 5.40 p. m., and for the first half hour the air was filled with sand and dust. The wind subsided at 8 p. m. A similar gale occurred on September 3. The sand storms on the east side seem to have been nothing but gales, which were, for some reason, unusually loaded with sand.

Gales were common during the entire residence in the valley. They were generally from the south and came on every three or four days. they were distinctly diurnal in their character, rarely lasting more than seven hours, and usually only two or three, and dying out toward midnight. The velocity was usually above 30 miles per hour, some reaching 45 miles or more, and one 51 miles per hour. They usually began suddenly and died out gradually. More than half of them were from the south, and four-fifths were from southern points of the compass.

Some of the gales from the south were more protracted and so unusually hot as to be specially designated by the observer as "hot winds." One on June 17 began at 10.40 a. m. and lulled at 6 p. m. It was one continuous hot blast, with a maximum temperature of 112°.6. The sky was partly covered with cirrus clouds, until later a dark stratus came down from the northwest.

Another hot wind set in at 1.35 p. m. on August 4 and continued, with lulls, until 11 p. m. of the 5th. The sky was cloudless and the heat intense (maximum 114°). The maximum velocity was 48 miles per hour at 4 p. m. of the 5th. Numerous whirlwinds were formed in the valley during the 5th and had sufficient power to take up loose boards to a considerable height. Other hot winds occurred on August 10, 26, and 29.

V.—THE AUTOMATIC REGISTERS.

The wind, temperature, and air-pressure were continuously registered during the five months that the station was occupied. The registering instruments worked well, were carefully attended, were compared with the standards at frequent intervals, and were reset when necessary. Their corrections, ascertained by the comparison with the standards, have been used in the compilations which follow. These corrections were always small, and there is no indication that the corrected readings do not as accurately as practicable represent the corresponding meteorological elements.

SUDDEN CHANGES ON THE REGISTER SHEETS.

The thermographic sheets present a very interesting and marked peculiarity. From about 10 o'clock in the evening until about sunrise they often show alternate waves of heat and cold. These were usually of from 3° to 5°. They were most common in the hottest weather, when there were often from three to five of them during each night. One of the strongest was on June 16, and this will serve as a type. At 2.43 a. m., local time, the thermometer was standing at 76°; it then began to rise and reached 83° (a rise of 7°) at 3.10 a. m.; it then fell slowly to 73° (a fall of 10°), which it reached at 4.50 a. m.; then it rose rapidly to 86°, reaching that point at 5.13 a. m. From this point it took up its regular daily progress. The temperature surges with their duration were as follows: A rise of 7° in 27 minutes; a fall of 10° in 100 minutes; a rise of 13° in 23 minutes. Meantime no appreciable change was made on the barographic sheet, and the anemographic sheet shows only a light and very variable wind.

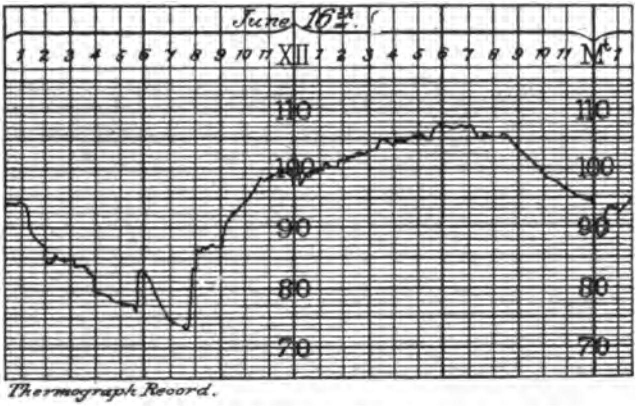
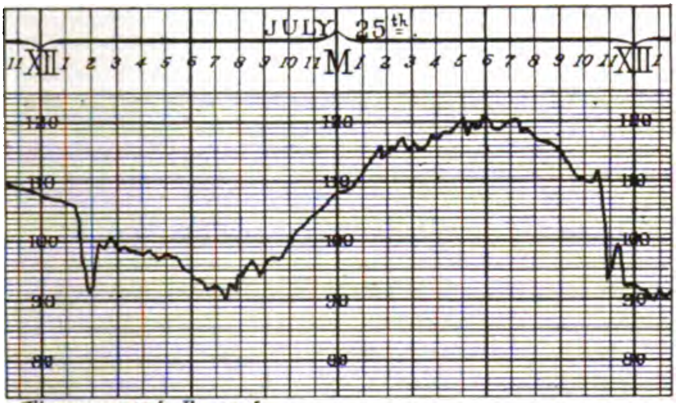


Fig. 6.

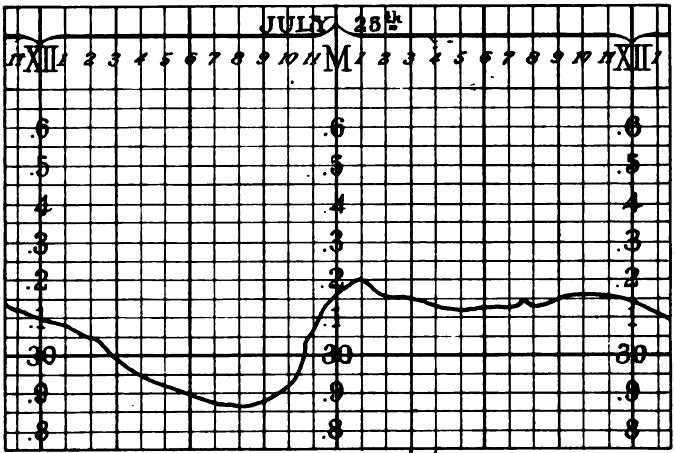
The upper part of the daily curve from about 10 a. m. to 4 or 5 p. m. shows a much larger number of minute changes back and forth of a degree or two. While the lower part of the diurnal thermograph tracing has a series of waves, the upper part has a series of ripples.

The waves might have been due to occasional clouds, though the records give no indication of this, and such sudden cloudings and clearings in this place are improbable. Further than this there seems no suggestion to make with regard to the cause of these waves and ripples.

A notable fall of temperature was that late in the evening of July 24. The thermometer was gradually falling, but at 10.33 p. m. it stood at 111°.8. It then began to fall rapidly, and at 11.10 p. m. it had descended to 91°.7, a fall of 20° in 37 minutes. It then rose again rapidly until at 11.23 p. m. it stood at 99°.7, when it resumed its regular diurnal course. In this case there were other changes. The wind, which had been rather sluggish for an hour or more, suddenly increased in velocity until at 10.50 p. m. it traveled at a velocity of 40 miles an hour for a short time. At 11.40 p. m. it again died down to 10 miles per hour. At about 10.35 p. m., also, the barometer began rising rapidly and passed from 30.03 to 30.13, reaching the latter point at 11.12 p. m. It then made a sharp turn and descended about .05 inch in the next hour. The sharp fall in the thermometer, the jump in the barometer, and the freshening of the wind are all familiar accompaniments of a thunderstorm. On turning to the daily journal of the observer we find the following record, where the hours have been changed to local time: "A thunderstorm began at 10.35 p. m., ended at 11.53 a. m."



Thermograph Record



Barograph Record

FIG. 7.

The thunderstorm followed by a tornadic storm of July 25 was accompanied by a similar fall of temperature. In this case it fell from 113°.0 at 7.53 p. m. to 92°.4 at 8.10 p. m., or 20°.6 in 17 minutes. It rose again, reaching 99°.2 at 8.33, when it fell again to 92°.5, reaching that point at 9 p. m., local time. According to the journal the violent wind came on at the very moment the sudden fall began, and the maximum velocity was at 8.08, or only two minutes before the end of this fall. The velocity in this case reached 60 miles.

The barographic curve gave a tremendous, but not so rapid, leap, quite unparalleled in magnitude in this record. It was gradually rising, when at 7 p. m. it began to rise rapidly from 29.90. At 9.13 it had reached 30.17, and by 11 p. m. it attained its maximum of 30.20. From this point it fell slowly for the next twelve hours. In about two hours the mercury rose over a quarter of an inch!

In general the barographic curve is very smooth. The thunderstorms are usually accompanied by a sudden jump, and the pressure remains slightly higher afterwards. Occasionally these jumps occur without any record of thunder, lightning, or rain by the observer. In general, considerable disturbances, relatively, may be shown on one instrument without appearing on the others, or being accompanied by phenomena which attracted the attention of the observer.

HOURLY WIND VELOCITIES.

Table VII gives the average hourly wind velocities. They are in hours of the 75th meridian time; to reduce them to local time, 2 hrs. 47 min. must be subtracted from the hours in column one.

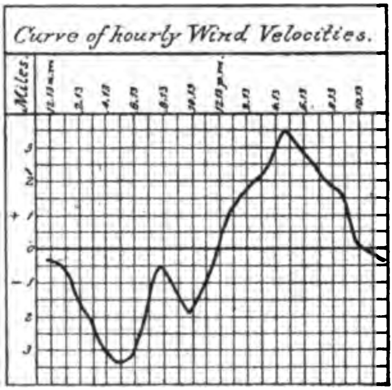


Fig. 8.

The progress of the velocities through the hours of the day is shown in the curve (Fig. 8) accompanying, plotted on the local hours. It presents several features of interest.

In the first place the minimum at about sunrise is more marked than usual. Generally the velocities are approximately equal in the hours after midnight, and it is not easy to fix the time of minimum. In this case the velocities decrease steadily and almost uniformly from the maximum to the minimum, a period of 12 hours.

The principal maximum falls toward sunset. This is much later than is usual. Over the United States generally the local time of maximum wind velocity is 2 p. m. Along the coasts, both Atlantic and Pacific, it falls later, reaching at the two diagonal regions (Washington and Oregon and the south Atlantic coast) an hour as late as 4 p. m. The arid region of the Southwest, from Denver southward and westward, also shows a disposition to delay the principal maximum, but in no case of the regular stations is it later than 4 p. m. In the case of Death Valley this is deferred until 5 p. m.

This retardation of the principal maximum is probably associated with another remarkable feature, and that is the secondary minimum at noon, which is plainly marked in the curve. This is an unusual phenomenon at the regular stations of the United States. At no other station is it so marked, though at half a dozen the velocity does not increase as rapidly at about, or soon after, noon as before or after this time, and in the summer months an actual minimum may be found. Among these stations are Memphis, Abilene, Palestine, Galveston, Yuma, and Red Bluff. At Death Valley this minimum is strongly marked, and it is not due to individual storms, morning and evening, but appears in each individual month, though it is strongest in June. This peculiarity may be due to the ascensional currents, which change at least some of the horizontal into vertical motion and which must form in this deep and bare valley. Such currents must be unusually strong, and the numerous cumuli and thunderstorms are caused by them. They should be most marked at the time of greatest heat (about 3 p. m.), but their greatest effect in dampening horizontal currents would be earlier, both because when once well started they would develop horizontal currents of their own, and because when well established they would cloud the valley and accelerate the heat maximum. Probably, if there were no ascensional currents in the valley, or if the valley were covered with dense vegetation so as to temper the heat, the curve of wind velocities would be as symmetrical here as is usual elsewhere, and the maximum would fall at 3 or 4 p. m. The establishment of the ascensional currents obliterates this maximum, but permits of one near sunset and another secondary at about 8 a. m. If such is the case the peculiarities of the curve to which reference has been made can all be traced to the character of the valley itself, and should be found in other deep, narrow valleys between bare and steep slopes.

HOURLY TEMPERATURES.

The average hourly temperatures are given in Table VIII. The curve is constructed on the local hours. The minimum falls at about 5 a. m., or near the time of sunrise. The curve rises steadily and rapidly to a maximum at about 3 p. m. It then falls as steadily to the minimum. The steady fall of the temperature during the night, like that of the wind velocities, is remarkable and must be due to the continued radiation to a clear sky from bare rock and sand and to the low relative humidity and dew-point. Dew does not form and the checking of the fall in temperature by the heat given out in the condensation of water does not occur. Eight of the hours (from 11 a. m. to 6 p. m., inclusive) have temperatures steadily above 100° F., and the mean maximum is 105°.5. In only four of the hours does the mean temperature stand below 85°.

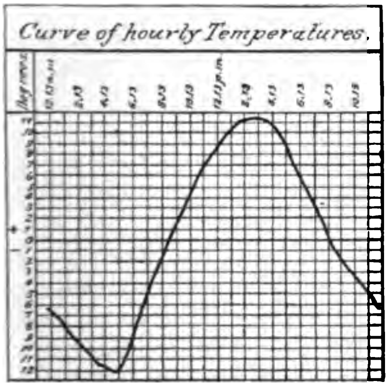


FIG. 9.

HOURLY PRESSURES.

The average hourly atmospheric pressures are given in Table IX. The curve corresponding to this table has been constructed on local hours.

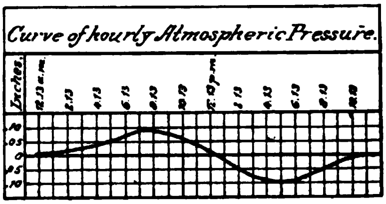


FIG. 10.

It is a remarkable curve for diurnal pressure, in that the range is very great and there is only a single and well-marked maximum and minimum. It bears a strong resemblance to the temperature curve reversed, except that its maximum is three hours later than the minimum temperatures and its minimum two hours later than the maximum of temperatures.

This at once suggests that this peculiar curve may be an illusory one, due not to the actual changes of daily pressure, but to some imperfection of the instrument whereby it described not a pressure curve, but a temperature one. The recording instrument was set with the mercurial barometer, corrected for temperature, at midnight April 30, when the observations began, and was compared twice daily (at the regular hours of observation). The readings show that it ran very evenly with the mercurial ones. As it happens, one of these readings was near the time of daily minimum of temperature (5.13 a. m.), while the other was near the maximum (5.13 p. m.). A systematic error in the barograph, due to over-compensation, is much less probable when the observations are checked at these hours than it would be at any others. But the best reason for thinking that this remarkable curve represents the actual change in pressure is to be found in the fact that similar curves have been obtained elsewhere.

The ordinary curve of daily pressure has two maxima and two minima which are fairly constant in time of occurrence, but very various in relative size. In the curve for Death Valley one of these has apparently disappeared, leaving a one-maximum curve instead of a two-maximum one. This seems to be the most striking example of this character which has yet been published, but it is not unique. It is a summer form, and belongs to the interior of great continents, especially to those stations which are both hot and dry. On the North American continent it is found from the Sierra Nevada and Cascades to the eastern slope of the Rocky Mountains and from the Mexican boundary to Fort Rae on Great Slave Lake. It probably extends into Mexico, but does not reach the city of Mexico, as the double maximum type is well marked there. It is also found on the Old Continent from Leh in Cashmere and Nertchinsk to Klagenfurth and Bucharest.

The use of the harmonic analysis in the study of the diurnal curve has shown the cause of its numerous variations. It appears that the actual curve is the resultant of the interference of at least two distinct periodic motions, one with a period of 12 hours, and the other
of 24.
semi-diurnal, is the one commonly recognized. It is
lar and the most general. Its amplitudes are greatest
and decrease with increase of latitude until they disap-

pear in high latitudes. The phases come on with great regularity in the local hours. It is a phenomenon of a general character and is often considered tidal.

The second, or diurnal curve, is less generally recognized, and the credit of having brought its distinctive features into plain view belongs to Doctor Hann.* It is nearly independent of latitude and altitude, but very sensitive to local conditions. The time of maximum is curiously constant. Out of 85 cases, scattered all over the world, in 35 the maximum fell between 4 a. m. and 6 a. m., and in 26 others it fell between 6 a. m. and 8 a. m. In 71 per cent. of all cases in which it appeared, and in all the remarkable cases, the maximum was between 4 a. m. and 8 a. m. In many of the others the smallness of the amplitude probably prevented exactness in the determination of the maximum.

The amplitude, or half-range, of this curve is very various. It is smallest at coast stations in high latitudes where the coasts are flat. In lower latitudes the coast stations have larger amplitudes, and it is appreciable even on the open sea. It is, however, greatest in valleys between mountains.

The station at Furnace Creek was in a valley of this sort, and the harmonic analysis, when applied to its records, shows that there is here a very clear and noteworthy case of a one-maximum curve of daily pressure. The resulting amplitude is 0.082 inch (or range of 0.164 inch). This amplitude is 2.1 millimetres, and it is worthy of note that the largest amplitude for these curves found by Dr. Hann was barely one millimetre, or less than half that of the curve in Death Valley. The latter was found at Cordoba, Argentina. The largest amplitudes given by Dr. Hann can be compared with that at Furnace Creek in the following statement, to which are added Yuma and Boston for comparison.

Amplitudes of single-maximum curves.

	Inch.
Death Valley (May–September, 1891)	0.082
Yuma (May–September, 1891)	0.045
Cordoba (5 years)	0.039
Bozen, Tyrol (2 years)	0.037
Yarkand (9 months)	0.035
Leh (short series)	0.034
Angola (2 months)	0.034
Mexico (3 years)	0.030
Boston (May–September, 1891)	0.017

The amplitude of the one-maximum curve is apparently larger in summer than in winter, and hence, if deduced for a year, those for Death Valley, Mexico, and Boston, as given above, would be somewhat decreased.

The local time of this maximum at Furnace Creek, as given by the analysis, was 6.05 a. m. At Yuma it was 5.15 a. m.

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* "Untersuchungen über die tägliche Oscillation des Barometers," 1889, pp. 13–16.

The semi-diurnal period is not easy to trace in the curve from the average of the observations, yet it can occasionally be detected on the barographic sheets. The analysis shows it distinctly and gives it an amplitude of 0.025 inch. The amplitude for the same months for Yuma was 0.023 inch, for San Diego, 0.015, and for Boston, 0.016. It is interesting to note that the amplitude for the one-maximum curve at San Diego for these months was only 0.001 inch.

VI.—CONCLUSIONS.

The principal features of popular interest in Death Valley are its excessive heat and dryness. The temperature rises occasionally in the shade to 122°; rarely falls at any time in the 5 hot months below 70°; and averages 94°. It is not only hot in summer but consistently hot, and the heat is increased by occasional hot blasts from the desert to the south. The air is not stagnant but in unusually active motion. Gales of a few hours duration are very common, and sometimes they produce sand whirls and sand storms. The heat and movement of the air together make this a very dry—an arid place—and this aridity in summer is almost as consistent as the heat. Rains may fall frequently in the mountains and occasionally in the valley, clouds are by no means lacking, and water can probably always be found at the depth of a few feet in the soil, yet the heat and wind together keep the surface very dry and the relative humidity low. Animal and plant forms are comparatively few, and the former are usually nocturnal to avoid the heat.

Both heat and aridity are increased by the character of the valley. It is narrow and deep, apparently the bed of an old sea, inclosed by high and bare mountains. The white and shifting sands become much heated under the noonday sun; the rest of the surface is in part salt and alkali, in part pebbly wash from the mountains, in part a loose, spongy earth, over which it is difficult to move. With the exception of a few springs, the water is bitter and unwholesome.

The effects of the extreme heat and aridity actually recorded, under conditions which afford full grounds for confidence, must be very serious, but tradition and common report add to these terrors others which are possible enough to deserve quotation.* It is said that the thermometer in the shade has sometimes reached 130°, and once touched 137°. Men exposed to the sun's rays in summer are said to be not infrequently driven insane, and the story is told of one man driving in on a load of borax who died suddenly with the water canteen in his hand. Meat slaughtered at night and cooked is spoiled the next morning; cut thin and dipped in brine it cures in the sun in an hour. A writing desk curled, split, and fell to pieces. Tables warp into curious shapes; chairs fall apart; water barrels, incautiously

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* These statements are for the most part from a long and interesting illustrated article in the New York *Sun* for February 21, 1892, signed by John R. Spears.

left empty, soon lose their hoops. But the most terrifying aspect of nature in the valley is reported in the cloud-bursts—a striking and not infrequent phenomenon over the dry Southwest, for which the conditions here are especially favorable. They are small and concentrated storms of the utmost fury, which gather suddenly about the mountains in the hottest weather. An ominous cloud forms with great speed, grows black and full of lightning, sags down to the mountains and releases a flood of water. The tales of the height of the resulting wave of water which comes down the cañon are so marvelous that they border on the mythical and need not be quoted.

The meteorological features of interest lie for the most part in those modifications of diurnal changes which are due to the topography. The range of temperature is unusually great; the hourly progress of the winds show curious changes in speed, in direction, and in temperature. The diurnal change in the barometer is the most characteristic of the form found in continental valleys. It is of the purest single-maximum type and has the largest amplitude known. With these features go those sharp thunderstorms limited to certain hours of the day, and daily gales and hot blasts.

It is also noteworthy that the absolute humidity here is fairly constant and is that belonging to that part of the world. The air in the valley is part of the general aërial ocean and this shows no sharp contrasts in its moisture contents, except where wind prevails across a mountain ridge. Here the prevailing winds are up and down the valley and its relative aridity is due to its higher temperature.

A few words may be given to the winter climate, concerning which there are no recorded observations. The physical conditions of the valley, however, supported by the statements of those who have prospected there in the winter, and of those who have resided there in connection with borax works, enables us to reach a fair idea of this season. For five years, beginning in 1883, about 40 men were employed there. The season began with September and ended in June. By them the climate was considered healthy. Ducks and other migrating birds, jack rabbits, and cottontails were reported as abundant, and the neighboring Piutes extended their migrations into the valley. Snowfalls occurred on the mountains, sometimes to the depth of several feet. Ice forms in, and extreme cold has been reported from, the neighboring, but higher, valleys. In fact the relatively clear sky and bare soil make this region a favorable spot for the fall of winter temperatures. At Yuma the lowest temperature often reaches 27°, and once descended to 22°.5.

In short, following the year through, and accepting the guidance of the observations, of the physical conditions, and of the reports of those who have lived there, it is safe to conclude that the winter must be cool and salubrious, with an inch or two of rain. The early spring and late autumn must be of moderate temperature, with clear delightful air and little rain; the autumn very dry; the summer, with May and September, as we know, hot and arid. While the diurnal changes are great, the annual must be very much greater. The winter mean temperature may be between 35° and 40°, and that of the year 58° or 60°.

TABLE I.—*Highest, lowest, range, and mean daily atmospheric pressure at Furnace Creek, Death Valley, Cal., from May 1 to September 30, 1891.*

Day of month.	May.				June.				July.				August.				September.			
	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.
	Inches.	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inches.*	*Inch.*	*Inches.*
1	30·12	29·84	·28	29·99	30·00	29·78	·22	29·89	29·98	29·78	·20	29·88	29·99	29·84	·15	29·92	29·99	29·81	·18	29·90
2	29·93	29·85	·18	29·86	29·96	29·78	·18	29·89	29·93	29·75	·18	29·85	30·06	29·89	·17	29·98	30·01	29·81	·20	29·91
3	30·02	29·83	·19	29·91	30·13	29·87	·26	30·07	29·92	29·71	·21	29·82	30·05	29·80	·25	29·94	30·03	29·82	·21	29·92
4	30·10	29·89	·21	29·98	30·23	30·06	·17	30·15	29·93	29·77	·16	29·85	29·98	29·76	·22	29·88	30·02	29·87	·15	29·95
5	30·06	29·86	·20	29·96	30·18	29·93	·25	30·07	29·97	29·80	·17	29·89	29·92	29·72	·20	29·83	30·23	29·97	·26	30·10
6	30·03	29·83	·20	29·94	29·99	29·73	·26	29·88	29·92	29·69	·23	29·82	30·04	29·84	·20	29·94	30·29	30·11	·18	30·20
7	30·01	29·87	·14	29·94	29·92	29·68	·24	29·82	29·90	29·74	·16	29·81	30·08	29·88	·20	29·99	30·19	29·97	·22	30·09
8	30·13	29·96	·17	30·04	29·84	29·59	·25	29·74	29·99	29·80	·19	29·90	30·07	29·83	·24	29·96	30·11	29·95	·16	30·03
9	30·11	29·96	·15	30·03	29·95	29·73	·22	29·84	30·07	29·85	·22	29·96	30·02	29·80	·22	29·91	30·09	29·85	·24	29·98
10	30·11	29·94	·17	30·03	29·91	29·70	·21	29·82	30·03	29·71	·32	29·90	29·98	29·82	·16	29·90	30·01	29·82	·19	29·93
11	30·07	29·93	·14	30·00	29·91	29·71	·20	29·80	30·00	29·80	·20	29·89	30·12	29·91	·21	30·01	30·11	29·89	·22	30·01
12	30·11	29·89	·22	30·01	29·91	29·65	·26	29·75	30·06	29·90	·16	29·97	30·10	29·87	·23	30·00	30·08	29·88	·20	29·98
13	30·03	29·87	·16	29·95	29·84	29·71	·13	29·79	30·06	29·85	·21	29·96	30·05	29·89	·16	29·98	30·08	29·87	·21	29·98
14	30·16	30·02	·14	30·09	29·96	29·80	·16	29·89	30·04	29·85	·19	29·95	30·10	29·88	·22	30·01	30·10	29·91	·19	30·01
15	30·23	30·03	·20	30·12	30·14	29·98	·16	30·05	30·02	29·80	·22	29·91	30·10	29·89	·21	30·00	30·06	29·85	·21	29·98
16	30·15	29·96	·19	30·07	30·13	29·91	·22	30·03	30·01	29·82	·19	29·92	30·20	29·98	·22	30·09	30·21	30·02	·19	30·12
17	30·15	29·95	·20	30·05	29·96	29·69	·27	29·85	30·01	29·85	·16	29·94	30·21	29·98	·23	30·10	30·24	30·10	·14	30·16
18	30·06	29·93	·13	29·99	29·79	29·64	·15	29·73	30·00	29·81	·19	29·93	30·03	29·83	·20	29·96	30·20	29·98	·22	30·10
19	29·98	29·77	·21	29·90	29·87	29·60	·27	29·75	30·01	29·77	·24	29·91	30·00	29·84	·16	29·92	30·09	29·84	·25	29·98
20	29·92	29·59	·33	29·81	30·05	29·73	·32	29·93	29·99	29·80	·19	29·90	30·15	29·94	·21	30·04	30·03	29·90	·13	29·95
21	30·14	29·87	·26	30·06	30·06	29·72	·34	29·92	30·02	29·79	·23	29·90	30·13	29·93	·20	30·04	30·13	29·94	·19	30·03
22	30·30	30·11	·19	30·20	29·82	29·65	·17	29·76	30·00	29·82	·18	29·92	30·13	29·90	·23	30·01	30·05	29·86	·19	29·98
23	30·18	30·01	·17	30·11	29·99	29·79	·20	29·88	30·02	29·80	·22	29·93	30·08	29·82	·26	29·96	30·18	29·98	·20	30·09
24	30·15	29·96	·19	30·07	29·93	29·65	·28	29·82	30·05	29·90	·15	29·97	29·95	29·73	·22	29·85	30·25	30·01	·24	30·15
25	30·11	29·89	·22	30·03	29·90	29·71	·19	29·79	30·17	29·87	·30	30·03	29·91	29·76	·15	29·82	30·22	30·03	·19	30·15
26	30·03	29·84	·19	29·94	30·08	29·86	·22	29·99	30·20	29·95	·25	30·07	30·01	29·85	·16	29·93	30·28	30·06	·22	30·17
27	30·08	29·92	·16	29·99	30·12	29·92	·20	30·02	30·12	29·79	·33	30·00	30·10	29·87	·23	29·99	30·23	29·98	·25	30·12
28	30·06	29·87	·19	29·98	30·07	29·81	·26	29·95	30·10	29·81	·29	29·97	30·06	29·80	·26	29·95	30·21	29·95	·26	30·08
29	30·11	29·92	·19	30·02	30·00	29·79	·21	29·90	30·00	29·80	·20	29·92	30·05	29·85	·20	29·94	30·02	29·48	·54	29·81
30	30·06	29·88	·28	29·94	30·00	29·81	·19	29·90	30·02	29·79	·23	29·91	30·05	29·87	·18	29·95	29·94	29·41	·53	29·68
31	29·94	29·83	·11	29·88	....	....	.....	....	29·92	29·78	·14	29·86	30·05	29·85	·20	29·95	....	....	.....	....
Average	30·08	29·89	·19	30·00	29·99	29·77	·22	29·89	30·02	29·80	·22	29·92	30·06	29·85	·21	29·96	30·12	29·90	·22	30·02

NOTE.—The values given above were obtained from a Richard's barograph, checked daily by comparison with a standard mercurial barometer. The barograph was set to agree with the readings of the mercurial instrument, corrected for instrumental error and reduced to 32° F. The barograph was compensated for temperature. No corrections for elevation have been applied. The "mean" is from the 24 hourly readings.

TABLE II.—*Daily extremes, range, and mean temperature at Furnace Creek, Death Valley, Cal., from May 1 to September 30, 1891.*

Day of month.	May.				June.				July.				August.				September.			
	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.	Max.	Min.	Range.	Mean.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1	106	70	36	89.0	89	60	29	75.5	122	89	33	106.5	116	83	33	103.2	118	81	37	102.3
2	104	79	25	89.5	90	66	24	78.5	122	92	30	108.0	118	82	36	103.6	119	81	38	103.4
3	99	70	29	87.7	90	69	21	79.1	120	91	29	104.8	119	84	35	104.5	116	85	31	103.2
4	102	77	25	90.8	100	66	34	85.2	118	91	27	105.1	118	87	31	103.4	115	92	23	103.8
5	105	78	27	92.4	106	72	34	91.3	116	95	21	105.7	114	89	25	100.8	110	88	22	98.0
6	105	79	26	93.4	111	78	33	97.2	114	89	25	101.7	109	78	31	94.5	100	78	22	89.1
7	96	76	20	85.5	111	85	26	97.5	109	84	25	96.8	108	74	34	93.1	112	82	30	97.1
8	94	62	32	79.5	109	83	26	94.6	109	76	33	92.8	113	73	40	93.3	112	86	26	98.3
9	98	70	28	85.5	102	79	23	91.6	106	82	24	93.4	117	77	40	100.0	115	85	30	100.8
10	101	64	37	86.0	106	70	36	91.5	109	81	28	94.0	118	77	41	103.3	111	88	23	98.8
11	100	75	25	89.1	104	82	22	90.7	106	84	22	94.5	114	92	22	102.3	105	75	30	91.9
12	96	78	18	86.8	101	73	28	86.7	109	81	28	97.2	115	93	22	104.1	107	82	25	93.8
13	88	71	17	81.0	94	72	22	80.8	114	72	42	96.3	113	96	17	102.9	105	81	24	92.8
14	85	61	24	74.5	96	68	28	83.6	116	82	34	101.6	113	85	28	99.3	103	79	24	90.1
15	94	61	33	81.1	103	78	25	91.2	118	81	37	102.7	110	91	19	100.0	100	75	25	84.9
16	101	67	34	86.8	108	73	35	93.7	119	92	27	105.9	102	79	23	90.8	89	68	21	77.8
17	100	73	27	88.7	113	84	29	98.8	120	88	32	105.7	104	75	29	89.2	96	70	26	82.3
18	103	68	35	88.9	106	82	24	94.2	120	99	21	108.6	108	83	25	96.0	99	66	33	84.9
19	103	79	24	90.9	104	77	27	91.4	120	94	26	106.5	111	86	25	99.0	103	75	28	89.3
20	98	79	19	86.2	105	81	24	92.0	119	88	31	106.5	110	77	33	97.2	99	79	20	88.2
21	78	54	24	69.4	113	69	44	94.0	121	88	33	106.4	117	75	42	99.0	98	72	26	84.9
22	90	59	31	75.9	110	84	26	97.2	119	96	23	107.7	120	80	40	102.7	97	74	23	85.1
23	95	70	25	83.0	104	80	24	92.9	120	88	32	107.8	120	82	38	104.0	98	70	28	85.3
24	97	72	25	84.9	109	75	34	93.3	121	95	26	109.1	122	85	37	105.1	97	76	21	84.9
25	100	71	29	87.0	105	83	22	94.8	121	91	30	105.6	122	87	35	108.4	95	72	23	82.1
26	101	78	23	90.7	105	82	23	93.6	115	88	27	100.0	121	89	32	104.8	97	58	39	79.5
27	99	73	26	85.0	112	77	35	95.8	112	85	27	94.7	119	88	31	105.2	100	59	41	80.9
28	95	70	25	81.6	119	79	40	100.8	107	79	28	92.7	117	83	34	104.4	103	67	36	84.3
29	92	59	33	76.8	121	89	32	108.2	112	84	28	99.2	117	87	30	104.7	106	65	41	87.2
30	94	69	25	80.0	122	96	26	108.0	114	87	27	102.5	118	86	32	104.7	82	72	10	78.8
31	92	67	25	78.4	......	......	......	....	116	80	36	102.3	120	81	39	103.5	......	......	......	....
Average	97	70	27	84.7	106	77	29	92.1	116	87	29	102.1	115	83	32	100.8	104	76	28	90.2

NOTE.—The daily extremes given above are the readings of standard self-registering maximum and minimum thermometers, such as are used at all Weather Bureau stations. The "range" is the difference between the highest and lowest temperatures registered. The "mean" is from the 24-hourly readings of a Richard's thermograph, checked daily by comparison with standard mercurial instruments. The thermometers were exposed in a "sod" shelter 6 feet above ground.

TABLE III.—*Relative humidity at Furnace Creek, Death Valley, Cal., at* 8 *a. m. and* 8 *p. m., 75th meridian time, from May* 1 *to September* 30, 1891.

Day of month.	May.		June.		July.		August.		September.	
	8 a. m.	8 p. m.	8 a. m.	8 p. m.	8 a. m.	8 p. m.	8 a. m.	8 p. m.	8 a. m.	8 p. m.
	Pr. cent.	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*	*Pr. cent.*
1	22	7	45	19	28	10	21	7	26	12
2	38	9	35	26	18	12	28	7	32	16
3	25	12	48	24	24	9	22	10	30	17
4	23	13	48	16	23	14	18	8	29	21
5	17	11	34	15	19	12	16	5	37	46
6	9	9	22	13	20	9	16	13	74	38
7	31	12	26	14	17	9	18	6	64	23
8	38	14	28	11	38	13	20	8	41	24
9	20	13	20	12	23	13	20	12	40	18
10	33	13	18	11	27	15	28	17	31	15
11	30	17	23	18	31	16	40	16	31	18
12	32	18	39	18	18	12	38	18	30	12
13	41	48	34	22	30	11	21	22	20	19
14	53	32	32	18	28	12	47	19	22	10
15	57	23	47	19	22	10	33	21	19	22
16	40	14	22	14	16	10	56	29	42	22
17	29	10	26	10	22	10	76	29	34	21
18	24	11	28	14	16	13	43	22	43	17
19	34	9	22	12	20	10	34	10	30	17
20	43	38	13	10	16	6	22	12	28	14
21	62	31	26	8	13	10	25	11	33	20
22	58	15	17	11	20	13	26	11	37	22
23	36	14	16	10	32	14	32	8	36	21
24	23	21	18	10	22	13	21	11	28	17
25	30	14	22	16	34	13	26	8	23	16
26	24	13	22	13	51	21	18	7	36	18
27	30	14	21	10	50	22	16	8	45	16
28	20	20	29	11	72	23	21	13	31	21
29	55	24	16	9	40	18	33	14	31	36
30	32	39	18	12	20	9	31	12	22	20
31	61	14	....	....	38	8	33	12	....	....
Average......	34	18	27	14	27	13	29	13	34	20

NOTE.—The values given above were obtained by the use of the whirled psychrometer in a "sod" shelter, 5 feet above ground; thermometers 6 feet above ground.

TABLE IV.—*Kind, amount, and direction (from) of clouds at Furnace Creek, Death Valley, Cal., May* 1 *to September* 30, 1891.

Day of month.	May.			June.			July.			August.			September.		
	Kind.	Amt.	Direction from.	Kind.	Amt.	Direction from.	Kind.	Amt.	Direction from.	Kind.	Amt.	Direction from.	Kind.	Amt.	Direction from.
1	cs.	2	calm	0	5	0	ks. k.	6	sw. nw.	0	0	0	0	0	0
2	c., cs.	4	w.	c., s.	0	calm	ks. k.	4	sw. w.	0	0	0	ks.	4	s.
3	0	0	0	nim. ks.	5	s. w.	cs. k.	5	sw., w. nw.	0	0	0	D'se hz., k.	4	s.
4	cs.	0	s.	0	4	0	c., ks.	8	w.	0	0	0	k.	5	sw.
5	0	0	0	cs.	0	w.	ks. k.	7	nw. s.	0	0	0	ks.	8	s., sw.
6	cs.	5	s.	0	1	0	0	0	calm	0	0	0	ks.	8	s.
7	0	0	0	0	0	0	0	0	0	0	0	0	c. s.	6	w. s.
8	0	0	0	cs.	0	sw.	0	0	0	0	0	0	s. ks.	9	sw. nw.
9	0	0	0	Lt. hz., cs.	0	nw.	0	0	0	0	0	0	k.	2	calm
10	cs.	0	s.	cs.	8	w.	0	2	0	ks., k.	5	sw.	k.	1	w.
11	cs., ks.	6	s.	cs., c. ks.	10	w. sw.	0	0	0	Lt. hz.	0	calm	0	0	0
12	k. k.	2	e. s.	ks.	8	sw.	0	0	0	k.	4	sw.	0	0	0
13	ks. cs.	10	sw. s.	ks.	8	nw.	0	0	0	ks., k., cs.	8	sw.	cs.	1	w.
14	ks.	8	w.	k.	6	w., nw.	0	0	0	s.	8	w., s.	0	0	0
15	0	0	0	cs.	6	nw.	0	0	0	k. s.	9	n. s.	ks.	4	s.
16	c. k.	2	w. n.	c.	5	w.	c. s.	1	w. nw.	c., ks.	9	nw.	cs. ks.	6	sw. w.
17	cs.	7	s.	c., kc. s.	5	w. nw.	c.	0	nw.	ks.	8	nw., n.	c. ks.	6	s. n.
18	cs., c.	1	w.	c., kc.	6	nw.	ks.	2	s.	k.	8	w., nw.	0	0	0
19	ks.	8	calm	0	0	0	0	0	0	c.	5	w.	0	0	0
20	ks.	10	se., w.	0	0	0	0	0	0	c.	1	w.	cs.	9	sw.
21	nim., ks.	8	nw.	0	0	0	cs.	5	sw.	0	0	0	0	0	0
22	0	0	0	cs.	0	w.	ks., k.	8	sw.	0	0	0	ks.	1	ne.
23	c.	4	calm	ks.	0	nw.	ks. k.	6	sw. s.	0	0	0	0	0	0
24	ks.	8	n., nw.	s.	4	w.	ks., cs. k.	9	s. sw.	c., ks.	5	w.	0	0	0
25	ks.	5	calm	0	0	0	c., cs., ks.	9	sw.	ks., c., k.	4	nw.	0	0	0
26	c. ks.	5	w. sw.	0	2	0	c., ks. s.	10	w. nw.	s.	0	w.	c.	3	w.

27..........	0	0	0	0	0	0	cs., k., s.	8	nw.	0	0	0	0	0	0
28..........	0	0	0	0	0	0	cs. ks.	5	sw. n.	c. k.	0	w. sw.	0	0	0
29..........	ks., cs.	0	se.	ks.	0	nw.	0	0	0	cs. k.	4	w. n.	0	2	0
30..........	ks.	8	calm	k.	6	nw., w.	0	0	0	k.	0	calm	ks.	6	sw.
31..........	ks.	10	nw.	....	....	....	0	0	0	0	1	0	....	....	....
Averages ..	ks.	3.6	s.	cs.	3.0	w.	ks.	3.1	sw.	k.	2.5	w.	ks.	2.8	s.

NOTE.—The *amount* of clouds given is the average for the day on a scale of 1-10, obtained from *frequent* eye estimates during the day. The *kind* of clouds given are those observed at the a. m. and p. m. observations and any others that called for special notice in the daily journal. Where clouds are reported but no amount is given, the average for the day was less than one-tenth.

TABLE V.—*Direction of the wind at 8 a. m. and 8 p. m., 75th meridian time, and average hourly velocity at Furnace Creek, Death Valley, Cal.*

Day of month.	May.			June.			July.			August.			September.		
	Direction.			Direction.			Direction.			Direction.			Direction.		
	8 a. m.	8 p. m.	Average hourly velocity.	8 a. m.	8 p. m.	Average hourly velocity.	8 a. m.	8 p. m.	Average hourly velocity.	8 a. m.	8 p. m.	Average hourly velocity.	8 a. m.	8 p. m.	Average hourly velocity.
			Miles.			*Miles.*			*Miles.*			*Miles.*			*Miles.*
1	se.	se.	6.9	ne.	n.	7.0	s.	nw.	4.0	ne.	s.	9.2	nw.	s.	4.8
2	s.	s.	12.7	n.	se.	9.0	se.	sw.	6.0	se.	s.	7.7	n.	s.	6.8
3	se.	s.	8.6	se.	sw.	7.0	se.	nw.	10.2	e.	s.	10.9	se.	s.	14.1
4	se.	s.	12.3	s.	sw.	3.0	se.	sw.	5.0	s.	s.	15.6	s.	s.	10.5
5	se.	se.	12.0	se.	s.	4.0	w.	s.	8.4	s.	s.	25.9	nw.	n.	11.0
6	e.	s.	14.3	s.	s.	14.7	s.	s.	15.2	s.	s.	11.4	n.	s.	4.0
7	s.	s.	24.9	se.	s.	14.7	s.	s.	19.7	sw.	s.	6.2	n.	s.	4.8
8	ne.	s.	6.0	se.	s.	14.7	se.	s.	14.2	e.	sw.	4.3	n.	n.	6.4
9	ne.	s.	6.9	nw.	nw.	13.5	se.	s.	12.1	nw.	s.	5.2	se.	s.	11.7
10	se.	w.	4.3	se.	s.	7.0	s.	s.	15.3	w.	s.	15.5	se.	sw.	14.0
11	se.	s.	10.0	se.	sw.	19.2	se.	s.	10.0	s.	s.	13.4	se.	s.	7.3
12	se.	s.	16.6	s.	sw.	15.9	n.	s.	8.3	se.	s.	9.8	s.	s.	15.6
13	s.	s.	21.2	se.	ne.	12.6	ne.	s.	6.0	s.	s.	17.1	s.	s.	23.5
14	s.	s.	7.0	se.	nw.	6.0	s.	se.	5.0	se.	s.	12.4	s.	s.	22.4
15	calm	se.	3.7	ne.	nw.	6.0	s.	s.	6.0	ne.	se.	11.8	s.	s.	21.7
16	sw.	s.	8.0	nw.	sw.	6.0	s.	s.	10.1	se.	s.	15.3	s.	s.	9.8
17	n.	s.	9.0	se.	s.	17.4	nw.	s.	7.6	se.	s.	4.5	n.	n.	7.3
18	s.	s.	6.0	sw.	sw.	15.5	se.	s.	11.3	w.	se.	8.0	ne.	s.	5.0
19	se.	se.	9.0	se.	ne.	13.7	s.	s.	11.9	se.	s.	11.1	n.	s.	9.0
20	se.	se.	16.4	e.	sw.	11.3	s.	s.	9.2	w.	sw.	4.8	s.	s.	17.0
21	n.	nw.	10.0	n.	sw.	10.1	s.	s.	8.0	e.	w.	3.3	s.	s.	13.8
22	se.	s.	5.0	sw.	s.	18.3	ne.	s.	8.0	s.	sw.	3.6	s.	s.	16.8
23	se.	ne.	9.0	n.	w.	10.1	n.	sw.	7.9	calm	s.	4.7	ne.	n.	13.4
24	n.	n.	8.0	s.	s.	11.0	sw.	sw.	7.5	s.	s.	4.6	e.	nw.	13.6
25	n.	se.	6.0	se.	w.	12.0	s.	s.	8.0	se.	s.	6.3	ne.	s.	8.0
26	se.	se.	6.0	n.	nw.	8.0	nw.	s.	9.4	se.	s.	7.0	ne.	s.	3.1
27	s.	se.	8.0	e.	sw.	3.9	se.	s.	8.9	s.	sw.	6.2	n.	sw.	2.3
28	se.	se.	16.3	se.	s.	3.8	se.	se.	6.0	s.	sw.	5.8	s.	s.	2.6
29	e.	se.	8.0	ne.	nw.	8.0	n.	s.	6.0	calm	s.	6.4	s.	s.	8.0
30	e.	e.	5.0	n.	nw.	8.7	se.	s.	7.0	calm	s.	6.4	s.	ne.	24.4
31	se.	n.	6.0	....	....	....	n.	s.	7.0	nw.	s.	4.5	....	....	....
Prevailing direction and average hourly velocity.	se.	s.	9.8	se.	s., sw.	10.5	s.	s.	9.1	s.	s.	8.9	s.	s.	11.1

NOTE.—The anemometer was exposed 2 feet and 7 inches above the gable of roof of building occupied as an office; its approximate height above ground was 22.6 feet. No corrections have been applied to reduce to true velocities.

TABLE VI.—*Five-day means of pressure, temperature, and wind at Furnace Creek, Death Valley, Cal., from May* 1 *to September* 30, 1891.

Date.	Pressure.	Temperature, degrees F.	Wind, average hourly velocity.	Precipitation, sums.	Relative humidity.	
					8 a. m.	8 p. m.
	Inches.	°	*Miles.*	*Inch.*	%	%
May 1-5	29.94	89.9	10.5	....	25	10
May 6-10	30.00	86.0	11.3	....	26	12
May 11-15	30.03	82.5	11.7	....	43	28
May 16-20	29.96	88.3	9.7	....	34	16
May 21-25	30.09	80.0	7.6	0.14	42	19
May 26-30	29.97	82.8	8.7	....	32	22
May 31-June 4	29.98	79.3	6.4	0.09	47	20
June 5-9	29.87	94.4	12.3	....	26	13
June 10-14	29.81	86.7	12.1	....	29	17
June 15-19	29.88	93.9	11.7	....	29	14
June 20-24	29.86	93.9	12.2	....	18	10
June 25-29	29.93	98.6	7.1	....	22	12
June 30-July 4	29.86	106.5	6.8	....	22	11
July 5-9	29.88	98.1	13.9	....	23	11
July 10-14	29.93	96.7	8.9	....	27	13
July 15-19	29.92	105.9	9.4	....	19	11
July 20-24	29.92	107.5	8.1	....	21	11
July 25-29	30.00	98.4	7.7	0.37	49	19
July 30-August 3	29.92	103.2	8.4	....	26	8
August 4-8	29.92	97.0	12.7	....	18	7
August 9-13	29.96	102.5	12.2	....	29	17
August 14-18	30.03	95.1	10.4	0.60	51	24
August 19-23	29.99	100.4	5.5	....	28	10
August 24-28	29.91	105.2	6.0	....	20	9
August 29-September 2	29.93	103.7	5.8	....	31	13
September 3-7	30.05	98.8	8.9	0.20	47	29
September 8-12	29.99	96.7	11.0	....	35	17
September 13-17	30.05	85.5	16.9	....	27	19
September 18-22	30.01	86.5	12.3	....	34	18
September 23-27	30.14	82.5	8.1	....	34	18
September 28-30	29.86	83.4	11.7	....	28	26
Averages	29.96	94.0	9.9	....	30	16

TABLE VII.—*Average hourly wind movement at Furnace Creek, Death Valley, Cal., from May* 1 *to September* 30, 1891.

Hours ending—	May.	June.	July.	August.	September.	May to September.
75th meridian time.	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*
Midnight	10.3	12.3	12.0	10.6	12.9	11.6
1 a. m	9.3	9.4	10.8	9.7	11.1	10.1
2 a. m	7.7	9.8	11.0	9.5	11.0	9.8
3 a. m	7.6	10.0	10.3	9.4	10.6	9.6
4 a. m	7.5	10.6	9.7	9.1	9.9	9.4
5 a. m	7.4	10.6	9.1	7.1	8.8	8.6
6 a. m	7.0	9.4	7.7	6.1	8.7	7.8
7 a. m	6.6	8.3	6.2	5.4	7.9	6.9
8 a. m	6.2	8.2	5.7	5.5	7.4	6.6
9 a. m	7.0	9.2	4.6	4.7	7.8	6.7
10 a. m	8.6	10.7	6.5	6.2	8.2	8.0
11 a. m	9.8	11.9	8.3	7.7	9.1	9.4
Noon	9.1	10.2	7.4	7.5	9.4	8.7
1 p. m	8.9	8.0	6.6	7.4	9.1	8.0
2 p. m	10.0	9.2	7.0	7.2	10.4	8.8
3 p. m	11.4	9.8	7.9	8.0	11.3	9.7
4 p. m	12.9	10.4	9.1	9.4	13.3	11.0
5 p. m	13.5	10.5	9.3	10.8	13.8	11.6
6 p. m	13.0	11.1	10.0	11.3	14.6	12.0
7 p. m	13.2	12.0	10.9	12.5	14.5	12.6
8 p. m	13.3	12.7	11.9	13.5	15.6	13.4
9 p. m	12.9	12.2	12.1	12.3	14.9	12.9
10 p. m	11.9	12.2	12.3	11.2	13.7	12.3
11 p. m	10.8	13.7	11.3	10.8	12.5	11.8
Average	9.8	10.5	9.1	8.9	11.1	9.9

TABLE VIII.—*Average hourly temperature at Furnace Creek, Death Valley, Cal., from May* 1 *to September* 30, 1891.

Hours ending—	May.	June.	July.	August.	September.	May to September.
75th meridian time.	°	°	°	°	°	°
Midnight	84.4	90.9	100.3	99.5	88.9	92.8
1 a. m	82.5	88.5	97.8	97.6	88.7	91.0
2 a. m	81.5	86.5	95.8	96.2	86.5	89.3
3 a. m	79.3	85.3	94.4	94.5	84.9	87.7
4 a. m	77.6	84.2	93.7	92.9	83.6	86.4
5 a. m	76.3	82.7	92.0	91.2	82.5	84.9
6 a. m	74.9	81.3	91.1	89.7	80.9	83.6
7 a. m	73.9	80.2	90.0	87.6	79.4	82.2
8 a. m	73.0	81.0	89.3	86.7	79.3	81.9
9 a. m	75.2	84.0	92.5	89.6	79.5	84.2
10 a. m	78.9	87.5	97.1	94.1	83.4	88.2
11 a. m	82.1	90.4	100.5	98.2	87.5	91.7
Noon	85.1	92.6	103.6	101.3	91.0	94.7
1 p. m	87.7	95.4	106.3	104.7	93.7	97.6
2 p. m	90.4	97.4	108.4	107.7	96.8	100.1
3 p. m	92.5	99.4	111.0	110.1	98.9	102.4
4 p. m	93.8	101.0	112.6	111.9	100.8	104.0
5 p. m	94.6	102.7	113.7	113.0	101.6	105.1
6 p. m	94.9	103.4	113.9	113.8	101.4	105.6
7 p. m	94.4	103.5	113.6	113.6	100.0	105.0
8 p. m	93.6	102.4	112.1	111.4	98.0	103.5
9 p. m	91.3	99.8	109.5	107.8	94.7	100.6
10 p. m	88.9	96.7	105.9	104.2	92.5	97.6
11 p. m	86.6	93.9	103.0	102.1	90.8	95.3
Average	84.7	92.1	102.1	100.8	90.2	94.0
Range	21.9	23.3	24.6	27.1	22.2	23.6

TABLE IX.—*Average hourly atmospheric pressure at Furnace Creek, Death Valley, Cal., from May* 1 *to September* 30, 1891.

Hours ending—	May.	June.	July.	August.	September.	May to September.
75th meridian time.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Midnight	29.960	29.847	29.889	29.926	29.993	29.923
1 a. m	29.978	29.861	29.906	29.938	30.005	29.938
2 a. m	29.994	29.875	29.924	29.951	30.0.5	29.952
3 a. m	30.001	29.864	29.928	29.960	30.020	29.959
4 a. m	30.006	29.895	29.936	29.968	30.028	29.967
5 a. m	30.012	29.905	29.942	29.977	30.035	29.974
6 a. m	30.025	29.915	29.952	29.987	30.038	29.983
7 a. m	30.033	29.930	29.967	29.994	30.048	29.994
8 a. m	30.052	29.951	29.972	30.011	30.064	30.010
9 a. m	30.068	29.969	29.993	30.035	30.086	30.030
10 a. m	30.078	29.981	30.004	30.050	30.104	30.043
11 a. m	30.079	29.984	30.004	30.064	30.108	30.046
Noon	30.070	29.972	29.993	30.047	30.109	30.038
1 p. m	30.057	29.957	29.979	30.033	30.090	30.023
2 p. m	30.038	29.939	29.963	30.006	30.059	30.001
3 p. m	30.006	29.915	29.931	29.982	30.027	29.972
4 p. m	29.982	29.886	29.902	29.948	29.991	29.942
5 p. m	29.956	29.856	29.868	29.914	29.960	29.911
6 p. m	29.933	29.831	29.842	29.885	29.937	28.886
7 p. m	29.914	29.808	29.818	29.868	29.929	29.867
8 p. m	29.906	29.798	29.813	29.862	29.924	29.860
9 p. m	29.906	29.797	29.819	29.864	29.936	29.864
10 p. m	29.921	29.806	29.833	29.876	29.957	29.879
11 p. m	29.941	29.825	29.861	29.903	29.982	29.902
Average daily	29.996	29.891	29.918	29.960	30.019	29.957
Daily range	0.174	0.187	0.191	0.192	0.185	0.186

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NOTES

ON

A NEW METHOD

FOR THE DISCUSSION OF

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BY

FRANK H. BIGELOW,
PROFESSOR OF METEOROLOGY.

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TABLE VIII.—*Average hourly temperature at Furnace Creek, Death Valley, Cal., from May* 1 *to September* 30, 1891.

Hours ending—	May.	June.	July.	August.	September.	May to September.
75th meridian time.	°	°	°	°	°	°
Midnight	84.4	90.9	100.3	99.5	88.9	92.8
1 a. m	82.5	88.5	97.8	97.6	88.7	91.0
2 a. m	81.5	86.5	95.8	96.2	86.5	89.3
3 a. m	79.3	85.3	94.4	94.5	84.9	87.7
4 a. m	77.6	84.2	93.7	92.9	83.6	86.4
5 a. m	76.3	82.7	92.0	91.2	82.5	84.9
6 a. m	74.9	81.3	91.1	89.7	80.9	83.6
7 a. m	73.9	80.2	90.0	87.6	79.4	82.2
8 a. m	73.0	81.0	89.3	86.7	78.3	81.9
9 a. m	75.2	84.0	92.5	89.6	79.5	84.2
10 a. m	78.9	87.5	97.1	94.1	83.4	88.2
11 a. m	82.1	90.4	100.5	98.2	87.5	91.7
Noon	85.1	92.6	103.6	101.3	91.0	94.7
1 p. m	87.7	95.4	106.3	104.7	93.7	97.6
2 p. m	90.4	97.4	108.4	107.7	96.8	100.1
3 p. m	92.5	99.4	111.0	110.1	98.9	102.4
4 p. m	93.8	101.0	112.6	111.9	100.8	104.0
5 p. m	94.6	102.7	113.7	113.0	101.5	105.1
6 p. m	94.9	103.4	113.9	113.8	101.4	105.5
7 p. m	94.4	103.5	113.6	113.6	100.0	105.0
8 p. m	93.6	102.4	112.1	111.4	98.0	103.5
9 p. m	91.3	99.8	109.5	107.8	94.7	100.6
10 p. m	88.9	96.7	105.9	104.2	92.5	97.6
11 p. m	86.6	93.9	103.0	102.1	90.8	95.3
Average	84.7	92.1	102.1	100.8	90.2	94.0
Range	21.9	23.3	24.6	27.1	22.2	23.6

TABLE IX.—*Average hourly atmospheric pressure at Furnace Creek, Death Valley, Cal., from May* 1 *to September* 30, 1891.

Hours ending—	May.	June.	July.	August.	September.	May to September.
75th meridian time.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Midnight	29.960	29.847	29.889	29.926	29.993	29.923
1 a. m	29.978	29.861	29.906	29.938	30.005	29.938
2 a. m	29.994	29.875	29.924	29.951	30.0.5	29.952
3 a. m	30.001	29.884	29.928	29.960	30.020	29.959
4 a. m	30.006	29.895	29.936	29.968	30.028	29.967
5 a. m	30.012	29.905	29.942	29.977	30.035	29.974
6 a. m	30.025	29.915	29.952	29.987	30.038	29.983
7 a. m	30.033	29.930	29.957	29.994	30.048	29.994
8 a. m	30.052	29.951	29.972	30.011	30.064	30.010
9 a. m	30.068	29.969	29.993	30.035	30.086	30.030
10 a. m	30.078	29.981	30.004	30.050	30.104	30.043
11 a. m	30.079	29.984	30.004	30.054	30.108	30.046
Noon	30.070	29.972	29.993	30.047	30.109	30.038
1 p. m	30.057	29.957	29.979	30.033	30.090	30.023
2 p. m	30.038	29.939	29.963	30.006	30.059	30.001
3 p. m	30.006	29.915	29.931	29.982	30.027	29.972
4 p. m	29.982	29.886	29.902	29.948	29.991	29.942
5 p. m	29.956	29.856	29.868	29.914	29.960	29.911
6 p. m	29.933	29.831	29.842	29.885	29.937	28.886
7 p. m	29.914	29.808	29.818	29.868	29.929	29.867
8 p. m	29.905	29.798	29.813	29.862	29.924	29.860
9 p. m	29.906	29.797	29.819	29.864	29.936	29.864
10 p. m	29.921	29.806	29.833	29.876	29.957	29.879
11 p. m	29.941	29.825	29.861	29.903	29.982	29.902
Average daily	29.996	29.891	29.918	29.960	30.019	29.957
Daily range	0.174	0.187	0.191	0.192	0.185	0.186

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 2.

NOTES

ON

A NEW METHOD

FOR THE DISCUSSION OF

MAGNETIC OBSERVATIONS.

BY

FRANK H. BIGELOW,
PROFESSOR OF METEOROLOGY.

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NOTES ON A NEW METHOD FOR THE DISCUSSION OF MAGNETIC OBSERVATIONS.

I.—INTRODUCTION.

The object of this Bulletin is to describe a new method of dealing with the observations of magnetic observatories, particularly such as use photographic traces for automatic records. In seeking to extract the meaning from these curves, for the development of certain terms which seem to occur in meteorology and in other branches of science, it was found necessary to adopt certain principles and devices which prove to have a practical value.

It is not primarily intended in this paper to develop in a complete form any of the conclusions to which we may ultimately come, but it has been found simpler to employ them in an example which illustrates the analysis of the observations. Hence the reader will keep in mind that the justification of any apparently unsupported statements may be looked for in other publications which are to follow this, and in such papers a reference will be made to this Bulletin for an explanation of the treatment of the data. It will be seen that, incidentally, some suggestions have been made regarding certain questions that have received the attention of magneticians.

In order to view the subject in its proper proportions it will be necessary to recall the main steps in a somewhat extended investigation, of which this forms only one stage. Broadly, the science of terrestrial magnetism divides itself into two parts, the first being concerned with the origin and conditions of the so-called permanent magnetism of the earth, including the asymmetric distributions and the secular variations of the same; the second dealing with the variations and the disturbances of the magnetic needle. Our own work has been confined almost exclusively to the second portion of the problem.

There are well-known mathematical discussions of the general problem which conclude that the larger part of the observed terrestrial magnetic field must be derived from sources within the surface of the earth, while a small part comes from regions outside this surface; in a word, that the permanent magnetism originates within, and the periodic variations without, the surface of the earth. The question then arises regarding the variations, whether they are caused by corresponding changes in the physical conditions of the atmosphere, or whether they are produced by cosmical influences emanating for the most part from the sun and the moon. At this place we interpose the remark, that the position is regarded as proven that the sun and the moon do not continuously influence the terrestrial field by direct action as magnets, in the inverse proportion of the cube of the distances, such action being without doubt inappreciable.

There have been two general lines of hypotheses regarding the variations, one in which they are referred to atmospheric fluctuations responding to the astronomical relations existing between the sun, moon, and earth; the other, by which they are supposed to arise from the electro-magnetic relations between the earth and the ether in which it rotates.

The first step in the method now to be presented was a discussion of the solar corona, deriving the material from the photographs of the corona during the eclipses of July 29, 1878, January 1 and December 22, 1889, these being the only ones available, so far as known, in which the filamentary structure of the rays is shown with sufficient clearness to admit of the measures that are required to illustrate the theory.

A preliminary paper[1] was published in October, 1889, wherein was developed the mathematical treatment of the subject, and a first approximation in a comparison of the observations with the theory was appended, the theory being that the solar corona exhibits the action of some force conforming to the law of the Newtonian potential in the case of repulsion. No attempt has been made to ascribe this force to a specific physical agency, though it is evident that it resembles closely the action of electricity and magnetism. This view was further developed in various papers,[2] with the following special results, the localization of the coronal poles upon the sun, the period of rotation of the same, the restriction of the bases of the visible coronal streamers to a narrow belt about ten degrees in width, the central line being about thirty-four degrees from the coronal poles.

The point at which this subject touches terrestrial magnetism consists in the recognition of the fact that the law of the coronal streamers is such that, when applied to the whole of the field about the sun, there must be some invisible stream lines, which emanating from the polar regions of the sun, after sweeping wide through space, in the region of the orbit of the earth, are at right angles to the plane of the ecliptic. For lack of a better mode to express our conception, we may speak of the ether in the region of the earth as strained perpendicularly to the plane of the ecliptic.

Working upon this fundamental idea that the ether may be strained in certain directions, in response to directive influences emanating

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[1] The Solar Corona, Discussed by Spherical Harmonics: Smithsonian Institution, Washington, D. C., 1889.

[2] Further Study of the Solar Corona: American Journal of Science, November, 1890.—The Solar Corona, an Instance of the Newtonian Potential Function in the case of Repulsion: American Journal of Science, July, 1891.—The Law of the Solar Corona: Publications of the Astronomical Society of the Pacific, November 14, 1891.—The Rotation Period of the Sun at Latitude 85°.5: Publications of the Astronomical Society of the Pacific, November 16, 1891.

from proper sources, we proceeded by assuming that the ether in the neighborhood of the earth was actually in such a condition of strain in three directions at right angles to each other, first, radially in the direction of the sun, second, perpendicular to the ecliptic, and third, along the line of the orbit; the final justification of these premises to depend upon the relation they bear to the observed quantities, inasmuch as there is little known to science that could suggest them by the *à priori* method.

Some of the logical consequences of this theory were developed very briefly, especially in their application to terrestrial magnetism, in two other papers.[3] It is one of the purposes of this paper to illustrate the fact that we possess definite evidence of the existence of these primary directed influences or fields, as they may be called. They are named the radiant field, the coronal field, and the orbit field.

The next inquiry was, what effect has the atmosphere and the rotation of the earth upon these fields; or, how do these uniform fields act in the region of the earth, considered as a spherical conductor, surrounded by a concentric spherical conducting shell of variable specific conductivity? If the earth were a homogeneous spherical conductor placed in a uniform field or a series of fields, and rotating while being translated through them, the problem, though complex, is analytically soluble; but the conditions not being simple it became of prime importance to discuss the modifications of the simple law introduced by the ever varying state of the atmosphere considered as a conducting medium. Hence the question had to be settled whether meteorology has anything to do with terrestrial magnetism or not.

As regards this great problem to which we have drawn attention, what we present at this time is preliminary, but it is also enough to strengthen the main lines of the theory, and by so doing promises much encouragement for work of this kind. It is hoped that the development of the case will not lead to any permanent difficulties that cannot be overcome, for the following reason—in a final analysis it appears that all these phenomena are probably to be referred to Newton's law. On its positive side this gives rise to gravitational phenomena, and on its negative side to electrical or magnetic phenomena. Since the elder branch of the science has been so faithful to the facts of nature, we may expect that the other will be equally comprehensive in its range and simplicity.

II.—THE DEFLECTING FIELDS.

The guiding idea that has been employed in the investigation is as follows: Surrounding the earth at any instant of time is a given magnetic field, or a field traversed by lines of magnetic force, which dif-

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[3] Bulletin No. 18 of the U. S. Scientific Expedition to West Africa: May 15, 1890.—Note on the Causes of the Variations of the Magnetic Needle: American Journal of Science, September, 1891.

fers from some primary or normal field by certain distortions. These changes from the geometrical type, referred to the suitable ideal premises, are produced by deflecting forces which are due to magnetic tensions. It classifies the conception to inquire how many of these deflecting forces, or how many fields of deflection, can be detected, and when we speak of fields, from this point onward, we wish to be understood as meaning the directions along which the deflecting forces act, no matter to what causes in nature they are to be ascribed.

We therefore enumerate the following deflecting fields, supposed to be known as—

I. Distributing the magnetism within the surface of the earth:
  1. The field perpendicular to the ecliptic.
  2. The field parallel to the axis of rotation of the earth.
  3. The asymmetric fields, due to the water and land areas of the crust of the earth, and the non-homogeneous structure of its interior.

II. Periodically disturbing the general field produced by those just mentioned:
  4. The annual deflection.
  5. The diurnal deflection.
  6. The lunar deflection.
  7. The solar deflection.

III. Spasmodically disturbing the field:
  8. The meteorological disturbance.
  9. Disturbances, directed
    (*a*) towards the sun;
    (*b*) perpendicular to the plane of the ecliptic;
    (*c*) along the orbit of the earth; all directions are to be taken as only approximately described.

We will limit the scope of this paper to the deflections 4, 5, 8, and 9.

THE ANNUAL DEFLECTION.

Since the earth, according to our view, is a conductor polarized in certain directions, which may be regarded as those of the observed poles of permanent magnetism at any epoch, and is placed in the above-mentioned uniform fields, the specific angles of entry and departure of the lines which are bent from the direction of the undisturbed uniform field into the directions induced by the presence of a spherical conductor in the uniform field depend upon the angle existing between the axis of polarization and the axis of the uniform field. Now, by the annual revolution of the earth about the sun this angle changes in the period of a year, and gives rise to the annual deflecting field.

THE DIURNAL DEFLECTION.

Of the three uniform fields at right angles to each other, the radiant field is usually much stronger than the others, in fact always so except during intervals of specific disturbance. This field is actually parallel to the plane of the ecliptic, positive in the direction of the sun, but in consequence of this diurnal rotation of the earth, in accordance with the mathematical principles developed (Bulletin No. 18, see note [3]), the field is apparently retarded through an angle depending upon the velocity of rotation and the specific conductivity of the earth. This angle appears conspicuously in our results, and has a value of about twenty-three degrees for the northern hemisphere. Since the magnetic poles of the earth do not coincide with its axis of rotation, the angular relations of the conductor as polarized are continuously changing, in respect to the field, in a period of twenty-four hours, and this causes the diurnal deflection.

At this stage of the development it would be mere speculation to attempt to inquire into the physical relations between this magnetic field and the sun's radiations. That there is such a connection appears to be substantiated by the computations. Electricity and magnetism have many common properties; that electricity and light are intimately associated appears also to be the outcome of scientific discovery; and now we have the third bond exhibited between magnetism and solar radiation. Hence it will not be going too far to presume that electricity, magnetism, and light are all manifestations of the activity of the ether. In fact all space, and all the matter in space, seems to be stressed through and through by directed influences, to which we give various names in the physical sciences. The importance of following up this connection between magnetism and sunlight is apparent.

THE METEOROLOGICAL DISTURBANCES.

It was seen, early in our study of the curves or traces produced by the magnetic instruments, that an elimination of the annual, the diurnal, and also the disturbance fields, would not fully account for the facts that were therein exhibited. There was a persistent and conspicuous swaying up and down of the traces of the horizontal, the declination, and the vertical curves, which seemed to be wholly independent of the periodic curves and even of the marked disturbances, inasmuch as this swaying property, relative to the base line, was as manifest on quiet as on disturbed days.

As a probable explanation of this fact we assumed that it was due to changes in the conducting capacity of the dielectric, or conditions of the spherical conducting shell surrounding the earth, that is, to the atmosphere, and that hence it was strictly a meteorological phenomenon associated with the passage of the high and low centers near the station of observation. If solar radiations are transmuted into magnetic forces at the earth, these fluctuations in the condition of the atmosphere which change the radiant effect of the sun will likewise alter the amount and direction of the resulting magnetic force at any point. What these physical conditions are still remains to be investigated. It will be possible in this Bulletin only to indicate the method of research.

THE DIRECTED DISTURBANCES.

The same method of treatment enables us to detect those directions in space from which the disturbances come to the earth, and from the discussion of all the important disturbances during four months of 1889 it is clearly seen that they are strictly confined to three directions, as stated above in (*a*), (*b*), and (*c*). The stronger the disturbances the more persistently they follow these directions; at certain parts of the field there is evidently a conflict of forces which produces a varying resultant; but these places of conflict only serve to heighten the contrast whenever the fields are acting simply by themselves. The field (*a*), directed along the radiant field, as modified by the lag produced by rotation, is clearly due to the radiations of the sun; the field (*b*), perpendicular to the ecliptic, is perhaps due to the spasmodic coronal action of the sun; the field (*c*), directed some degrees westward of that part of space to which the earth is moving, also shows the same lag angle as field (*a*); it appears on the dark side of the earth, and may be due to some type of induction not as yet clearly analyzed.

I now proceed to a brief description of the mode of treating the observations, giving a simple example of the same by way of illustration.

III.—THE COÖRDINATES AND FORMULÆ.

It is proposed to obtain residual ordinates to the horizontal force, the declination, and the vertical force, which will be applicable respectively to the fields that have been described. For the variation of ordinates measured on the curves is in reality an integration of the combined effect of all the fields acting simultaneously. We assume a system of rectangular coördinates,

X, positive north in the plane of the horizon of the station, and in the plane of the mean magnetic meridian of the year;

Y, positive west and perpendicular to X, and also in the plane of the horizon;

Z, positive downwards along the normal perpendicular to the plane of the horizon.

Hence the magnetic azimuth is counted in the direction N, W, S, E, and for magnetic altitude + means that the force acts beneath the plane of the horizon, and —, that it acts above it.

If we take $\varDelta$H, the uncorrected residual for the horizontal force, $\varDelta$D, the uncorrected residual for declination, and $\varDelta$V, the uncorrected residual for the vertical force, we can compute a value corresponding to them, dx, dy, dz, from which will be obtained,

$\sigma = \sqrt{dx^2 + dy^2}$, the component of the total deflecting force on the horizontal plane.

$s = \sqrt{dx^2 + dy^2 + dz^2}$, the total deflecting force acting in space.

$\tan \beta = \frac{dy}{dx}$, where β is the azimuth of the deflecting force.

$\tan \alpha = \frac{dz}{\sigma}$, where α is the altitude of the same.

The labor of computing σ, s, α, β by squares or logarithms is so great, in view of the large amount of such work needed, that a diagram scale was constructed which practically reduces the time required to one-fourth of that by the first method, the accuracy being easily within one unit.

On a card is drawn a square 10.8 inches on the side, in which is inscribed a circle divided into half degrees, and numbered on each degree. The radius is divided into 200 units. The surface of the large square is subdivided into small squares, the sides of which are one-twentieth of the radius; also a series of concentric circles, whose radii differ by the same amount, is spread over the area; and radii are drawn in for every tenth degree, extending from the fifth to the twentieth circle. All the quadrants are numbered fully, so as to render it easy to plot in a point whose coördinates are given. For numbers up to about 200 the scale admits of direct use; for larger numbers the coördinates are reduced by a convenient factor, the final linear dimension being restored by this factor, the angle, of course, being the same in either case. Practically, one enters dx, dy, and reads off σ β directly; reënters σ, dz, and reads off s, α. Using a stylus and estimating by the eye, the results flow very rapidly from it.

The change of $\varDelta$H, $\varDelta$D, $\varDelta$V, to dx, dy, and dz, requires some explanation. The coördinates are chosen so that a positive value of these residuals indicates an increase of force in the positive direction of these axes. If the ordinates are taken directly from the photographic traces some reductions are necessary before they are available. The instrumental values must be reduced for the temperature coefficient in the case of $\varDelta$H and $\varDelta$V, the temperature not affecting $\varDelta$D. The values of $\varDelta$H, $\varDelta$V, in terms of millimeters, must be transposed to the corresponding values of the absolute force, as determined by a set of instruments for this purpose, and the coefficient of the value of one millimeter in terms of absolute force for H and V must be known. Since $\varDelta$D is an angle it must be translated into a corresponding W and E force. Now the mean horizontal force for the year, H_0, may be taken as the base of a triangle of which the altitude is determined by the angle ΔD, hence $dy = H_0 \tan \Delta D$. An auxiliary table may be constructed for any station, as has been done for Washington, by means of which the change can be effected at a glance from the value of ΔD in minutes of arc to the W — E deflecting component *dy*.

I will say that all the results obtained have been wholly corrected for the temperature of the magnet, and that no objection can properly be interposed into my discussion on that account. As far as possible I have used the reduced final values of the instruments as they appear in the publications of the U. S. Magnetic Observatory for the years 1889 and 1890 (from advanced sheets) and 1891 (from manuscript). I take the opportunity to acknowledge the obligations that the Bureau is under to the courtesy of the Navy Department, especially to Commodore George Dewey, Chief of the Bureau of Equipment, to Captain F. V. McNair, Superintendent of the U. S. Naval Observatory, and to Ensign J. A. Hoogewerff, U. S. N., in charge of the U. S. Magnetic Observatory, whereby it has been possible to undertake this work. In the case of other observatories it has been necessary to depend upon the results appearing in the volumes containing their reports. As has been seen, the two important elements of transposition are the temperature coefficient and the value of one millimeter ordinate in terms of the absolute force. It is precisely these to which Ensign Hoogewerff has paid the closest attention, and the rigid scrutiny to which it has been necessary to submit the curves and the reduced values, seems to justify us in placing confidence in the efficiency of the work he has done.

THE TREATMENT OF THE OBSERVATIONS.

As a starting point in the analysis of these residuals, we take the annual mean value of the H, D, V; that is, the mean derived from the twenty-four observations for each day, summed for each day, and again summed for the whole year. The range of 365 days is broken up into the usual twelve monthly groups, by summing for the respective days of the month. Subtracting the mean of the year from the mean for the month, we obtain the residuals pertaining to the annual curve. By plotting these and running smooth curves through them, the annual deflection at the individual day is secured.

If we take the means by months for each of the twenty-four hours and subtract from them the mean of the month, we obtain the mean residuals of the diurnal curve for the month. In passing from month to month we could also construct average curves, one for each of the twenty-four hours, by which could be obtained the diurnal curve for any specified day, but this refinement of calculation has not been attempted.

The question next arises as to the proper dealing with days of marked disturbance, one that continues to puzzle magneticians. I have, in the use of observations, restricted myself to the striking out of not more than one in ten of the extreme values, obtained by reading the ordinates of the curves for the hours, just as they occurred, even if upon the crest or the bottom of a disturbance. When we are seeking a normal curve this is evidently incorrect, limiting the ordinates to twenty-four points, and it could be improved only by using a very large number of such points, or practically integrating the area included between the curve and the base line. As this is hardly practicable, I shall take the opportunity further along in this paper of suggesting a device for accomplishing something better than the 24-point method.

If, again, we subtract the mean of the month from the mean of the twenty-four hours for each day, we obtain what I regard as the meteorological element in the problem, this residual being the mean amount by which the diurnal curve for the day lies above or below the mean diurnal curve, except so far as affected by the ordinates of marked disturbances, which of course ought to be eliminated, and which are partially compensated by the average of the disturbance flux and reflux for the day. This meteorological residual is the mean for the day, but, properly, it should be distributed through the day, unless it is intended to make a comparison between the mean of the magnetic-meteorological residuals, and the meteorological variations as disclosed by the instruments for the mean of the day. I shall show, however, a way in which this residual can be distributed along the day, and then comparisons can be made with the meteorological elements for any specified hour.

Finally, if from the actual ordinates for any moment the total deviations accounted for up to this point, that is, the annual plus the diurnal plus the meteorological residuals, be subtracted, we shall have the residual of the disturbance proper, and this apparently exhausts the problem. It remains, therefore, to explain how we have endeavored, practically, to separate these residuals. The example is taken from the volume of the Washington observations, 1886, Appendix I, entitled "Magnetic Observations at the U. S. Naval Observatory, 1888–1889," and we select the month of March as an average case. It should be said that the computations were made before the relation with the meteorological elements was investigated, and that no changes have been made in the figures as here reproduced. A tabular presentation of the computations is introduced from time to time, which will be easily understood from the arrangement and the adjacent line of thought.

TABLE I.—*Horizontal*

The figures given in the table are millionths of a dyne, which added

.198000+

Day.	A. M.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	405	409	687	767	739	768	782	617	618	599	693	670
2	712	735	749	735	807	736	764	745	709	662	620	605
3	802	826	816	807	803	831	794	714	687	649	602	611
4	846	813	775	808	837	851	837	861	815	862	867	805
5	874	846	855	851	847	889	885	814	773	806	857	890
6	894	1017	819	866	820	703	905	698	628	206	586	652
7	853	708	567	708	680	685	798	821	705	710	705	611
8	802	943	797	821	817	841	826	794	719	644	649	649
9	789	813	836	789	837	828	832	771	702	683	674	683
10	847	856	861	861	885	857	843	815	858	722	637	651
11	842	828	847	861	862	881	876	843	774	774	779	713
12	1041	980	928	975	986	939	925	896	855	860	794	752
13	812	859	765	878	808	874	931	982	889	885	856	833
14	785	781	781	795	833	805	796	749	717	707	674	684
15	795	814	833	856	852	866	843	740	708	661	914	679
16	824	839	881	848	848	871	867	792	759	698	688	669
17	868	849	863	896	877	849	882	830	727	623	713	825
18	596	615	620	714	718	690	596	526	526	521	577	......
19	776	804	799	813	827	837	813	780	729	710	691	691
20	786	819	805	819	814	838	791	781	735	617	565	655
21	768	862	815	825	834	834	834	754	726	693	651	552
22	953	901	713	661	798	774	802	760	708	567	572	581
23	761	780	846	789	799	761	756	799	728	662	695	761
24	800	879	832	832	851	738	785	814	795	781	677	649
25	768	744	768	805	791	791	772	711	716	763	739	697
26	863	816	830	830	830	820	830	797	736	712	712	750
27	713	765	737	732	788	774	784	680	619	718	788	793
28	451	587	587	559	677	695	498	818	625	545	503	498
29	701	790	701	701	711	743	772	645	518	452	438	368
30	730	796	796	806	801	782	796	735	650	500	486	509
31	830	807	830	802	778	816	807	727	609	557	595	628
Mean..	783	803	785	800	811	805	807	768	712	663	679	670

***force*, *March*, 1889.**

to .198000 dyne, give the absolute horizontal force in C. G. S. units.

.198000+

Day.	P. M.												Mean.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
1	610	563	699	699	794	738	747	757	706	678	729	729	675
2	658	691	550	696	786	824	819	786	782	782	792	787	731
3	655	772	871	833	858	839	839	839	849	779	798	845	780
4	830	821	882	900	939	930	925	831	846	832	818	921	852
5	858	896	915	967	935	1015	968	953	743	419	541	658	836
6	653	488	653	761	814	814	786	804	801	772	707	594	727
7	668	654	664	800	707	655	829	853	802	778	882	755	733
8	739	913	927	847	797	768	768	815	802	816	807	793	796
9	689	717	773	825	845	859	864	845	865	879	851	851	796
10	667	690	775	840	856	865	870	856	852	861	857	838	813
11	845	892	939	902	908	926	922	922	913	890	866	866	861
12	790	880	983	1007	904	636	730	918	919	872	863	849	887
13	857	872	716	669	638	741	652	595	507	671	671	624	774
14	755	779	784	812	836	813	747	799	828	833	800	889	783
15	690	798	727	831	851	860	888	884	842	828	838	828	809
16	787	853	890	876	857	829	806	857	881	890	900	895	829
17	835	821	1206	835	445	—185	149	—039	356	426	454	595	658
18	662	714	784	841	855	831	850	855	826	737	714	789	702
19	701	771	799	827	823	715	818	809	809	804	846	804	783
20	702	725	739	739	706	810	749	777	758	739	711	753	747
21	585	731	717	712	811	717	820	839	829	858	938	905	775
22	605	732	793	760	647	624	628	671	713	802	779	773	722
23	799	803	817	831	822	836	860	869	836	822	822	784	793
24	743	800	847	879	922	818	832	842	785	724	738	842	800
25	749	782	848	843	815	801	791	805	815	796	815	824	781
26	900	947	924	900	858	830	708	731	722	698	......	......	806
27	962	793	864	915	925	859	864	835	751	605	976	643	787
28	822	493	757	719	738	808	686	677	719	719	639	625	644
29	725	762	767	711	762	711	795	814	823	828	837	847	705
30	524	538	608	688	768	754	782	796	810	796	801	806	711
31	633	741	830	835	811	816	821	830	830	816	783	797	764
Mean ..	726	756	808	816	808	770	784	788	785	769	786	784	769

TABLE II.—*Declination*,

Ordinates, expressed in minutes of arc, taken from the daily declination traces.
declination at

Base-line value

Day.	A. M.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
	′	′	′	′	′	′	′	′	′	′	′	′
1	64.2	68.1	68.4	67.6	68.2	69.1	71.6*	77.4*	71.4*	72.0*	69.0	70.5
2	68.2	67.4	67.7	67.3	67.6	69.6	69.0	67.0	66.3	68.1	69.9	72.1
3	69.0	69.9	70.4	68.4	67.5	67.8	67.4	67.0	66.4	67.0	68.9	70.4
4	68.7	67.6	67.1	67.1	67.0	66.9	68.0	65.7	66.0	67.8	68.9	70.7
5	67.7	69.0	67.1	67.9	69.1	67.4	67.3	66.8	67.5	67.8	68.4	69.8
6	70.2	66.3	64.2*	67.1	73.5*	72.0*	69.1	71.0*	71.6*	75.5*	74.6*	....
7	66.6	66.8	70.1	68.4	69.2	69.4	68.0	66.4	66.6	67.8	67.7	69.6
8	68.4	71.1	71.1	68.1	68.1	68.4	68.1	67.0	68.0	67.9	69.9	72.3
9	68.9	69.0	69.8	69.0	69.0	68.6	68.0	67.0	66.7	67.7	69.4	....
10	69.2	68.9	68.7	68.6	68.2	68.9	68.4	66.4	66.0	66.2	68.0	70.2
11	69.0	69.2	68.2	68.2	68.4	68.4	68.1	67.1	67.4	67.8	69.1	....
12	68.6	66.9	67.0	67.0	66.5	67.9	67.5	66.9	65.4	67.0	68.2	70.0
13	68.1	69.1	68.4	68.2	68.2	68.1	67.6	67.3	66.2	66.0	67.7	69.3
14	69.0	68.3	68.3	68.8	68.6	68.6	68.0	67.3	67.2	67.7	69.2	71.4
15	69.1	69.1	68.8	68.3	67.8	68.0	66.1	66.2	65.2	66.6	69.5	71.0
16	67.7	72.1*	68.3	67.7	67.8	68.0	67.0	67.0	66.7	67.7	70.2	71.6
17	68.2	68.1	68.0	68.0	67.5	67.9	66.1	64.3	64.4	66.2	69.8	71.7
18	67.1	68.2	68.0	68.5	69.0	68.0	65.9	64.7	65.2	....	69.9	....
19	69.0	68.9	68.3	68.1	68.0	67.3	66.3	65.0	64.9	65.9	67.8	69.9
20	68.4	68.8	68.1	68.0	67.6	68.0	66.3	65.7	65.6	65.5	68.0	69.9
21	69.8	68.8	68.3	68.9	68.6	68.4	67.1	66.6	67.1	66.8	68.7	72.0
22	66.3	64.0*	67.2	64.3*	65.6*	65.9*	65.5	65.2	66.0	66.1	69.5	71.6
23	68.7	68.6	70.0	68.2	68.1	68.0	68.0	67.4	66.6	66.5	68.4	69.7
24	68.8	68.2	68.1	68.0	67.2	69.1	70.9	67.6	67.0	67.6	69.1	70.8
25	66.2	68.3	67.5	67.9	67.0	68.1	67.0	66.7	67.1	67.2	68.8	70.7
26	69.1	68.5	67.9	67.9	67.6	67.6	67.1	66.2	65.8	66.2	68.8	72.1
27	67.6	68.0	68.1	68.2	68.1	67.0	66.1	65.4	66.0	66.4	69.2	71.0
28	60.3*	68.8	64.4*	67.4	68.8	66.7	66.0	69.4*	64.0	66.0	70.1	75.0*
29	68.4	69.2	68.7	68.7	68.8	67.6	65.1	64.5	66.4	66.4	69.9	74.4*
30	68.4	70.3	67.2	66.1	68.2	68.8	66.7	64.5	64.9	65.8	67.4	68.8
31	69.2	68.9	68.8	69.5	70.1	68.2	66.9	65.0	65.1	65.9	68.2	71.4
Mean..	68.3	68.7	68.4	68.0	68.0	68.1	67.3	66.3	66.1	66.8	68.9	70.7

***March*, 1889.**

The ordinate for any hour added to the base-line value gives the absolute westerly that hour.

$=2^\circ\ 51'\ 31''$

Day.	P. M.												Mean.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
	′	′	′	′	′	′	′	′	′	′	′	′	
1	74.0	75.7*	73.2	70.3	69.0	68.9	68.7	68.5	68.7	69.9	69.1	69.3	70.01
2	73.2	74.0	73.6	71.5	69.9	69.3	68.9	68.8	68.9	68.9	69.0	69.2	69.39
3	72.3	72.5	72.4	71.3	70.3	69.6	69.3	69.1	69.3	69.0	69.6	70.3	69.38
4	71.7	71.8	71.4	70.3	69.6	69.5	69.1	68.9	68.9	69.0	68.7	68.6	68.71
5	70.7	70.9	70.5	69.8	69.9	70.3	69.9	69.2	69.5	64.0*	66.1	66.0	68.44
6	72.6	72.6	71.1	70.6	69.9	69.1	68.6	67.7	68.1	67.1	65.9	64.4*	69.69
7	71.1	72.0	72.3	70.8	70.1	68.9	69.0	68.9	68.6	67.2	65.7	68.7	68.75
8	73.1	72.5	72.1	70.7	70.2	69.5	69.0	68.6	67.6	66.2	68.7	69.0	69.40
9	72.4	72.7	71.9	70.8	69.7	69.4	69.2	69 0	69.0	68.9	69.1	69.1	69.32
10	71.8	72.1	72.9	71.9	69.7	69.2	69.1	69.0	69.3	69.0	69.0	68.6	69.07
11	70.5	71.1	71.3	71.3	72.1	71.7	70.0	69.2	69.1	68.7	68.4	68.5	69.14
12	70.9	71.0	70.3	69.5	69.5	69.6	69.3	69.0	69.0	68.3	68.7	68.5	68.44
13	71.2	71.9	73.1	77.0*	72.9	73.2*	73.3*	73.0*	70.0	63.5*	68.5	68.9	69.61
14	73.2	72.1	71.9	71.1	70.1	69.9	69.0	69.0	69.0	68.5	67.4	68.4	69.25
15	72.3	73.3	73.0	70.7	69.7	69.4	69.0	68.7	68.8	69.0	69.7	67.8	69.05
16	72.2	72.6	72.3	70.9	69.6	68.6	68.3	68.6	68.5	68.7	68.6	68.5	69.13
17	74.1	73.1	74.1	73.5	73.9	71.0	72.0	71.8	68.0	66.9	71.2*	63.8*	69.32
18	72.0	72.1	72.0	71.0	70.0	69.3	69.0	68.9	68.7	67.0	68.7	67.3	68.66
19	71.8	72.5	72.1	71.6	70.6	69.6	69.2	68.7	68.8	64.9	67.3	69.0	68.56
20	72.6	72.7	73.5	73.1	73.4	70.8	70.5	69.2	69.0	67.8	69.1	69.0	69.15
21	73.9	74.4	75.2*	74.0	72.0	70.6	69.9	68.8	69.5	69.1	68.8	68.9	69.84
22	72.9	72.1	73.4	71.8	71.9	70.9	63.5*	68.9	70.2	69.4	68.9	68.8	68.33
23	70.8	71.0	70.7	70.4	69.7	69.4	69.2	68.9	69.0	68.8	69.3	68.7	68.92
24	71.1	71.5	71.4	71.0	70.4	70.4	69.8	69.6	69.8	68.3	69.9	71.0	69.44
25	71.0	71.3	71.7	70.4	70.0	69.7	69.7	69.1	69.2	69.1	69.0	68.9	68.82
26	71.8	70.8	71.4	70.8	70.5	70.2	68.9	66.8	68.6	68.3	……	……	68.77
27	71.6	72.5	72.4	71.4	70.5	70.6	70.1	70.7	64.9*	66.3	57.4*	65.6	68.55
28	73.6	75.9*	72.2	73.2	71.2	69.7	69.9	66.3	65.2*	67.5	68.4	68.4	68.68
29	74.3	73.6	73.9	72.6	70.4	68.5	69.6	69.4	69.2	69.3	67.2	68.2	69.35
30	70.5	71.8	72.4	71.8	70.6	69.5	69.1	68.6	69.0	68.9	68.9	69.0	68.63
31	73.4	74.5	74.6	73.0	71.1	70.3	69.6	69.3	68.9	69.0	69.0	68.9	69.53
Mean ..	72.2	72.3	72.2	71.3	70.3	69.8	69.4	68.9	69.0	68.2	68.5	68.6	69.08

TABLE III.—*Vertical*

The figures given in the table are millionths of a dyne, which,

.581000+

Day.	A. M.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	163	221	237	242	238	229	197	187	183	170	156	104
2	243	230	202	236	241	242	248	248	240	212	165	122
3	223	200	186	191	192	203	204	185	138	115	092	111
4	270	266	286	291	301	298	299	279	261	257	254	249
5	259	260	280	280	281	263	269	254	255	261	248	238
6	339	206	183	279	208	151	200	243	259	284	290	266
7	156	109	177	321	312	318	353	357	349	350	308	274
8	399	371	344	363	383	403	428	428	410	377	306	268
9	355	351	342	352	353	359	360	355	342	309	238	214
10	358	364	365	370	371	372	387	373	355	303	260	246
11	352	349	350	354	365	366	372	372	344	326	312	312
12	303	319	329	334	345	350	342	327	309	267	230	186
13	230	193	179	155	161	162	182	187	188	179	176	176
14	229	273	279	274	280	295	301	301	302	293	304	323
15	271	272	273	273	279	289	305	295	301	292	264	245
16	246	247	243	267	273	283	299	279	280	267	230	225
17	244	245	246	246	247	244	250	249	198	122	118	118
18	306	283	284	284	261	242	267	258	225	159	126	150
19	199	209	220	225	226	241	247	237	210	187	149	144
20	246	251	252	252	258	274	289	265	252	248	215	206
21	273	249	249	254	254	259	259	249	220	196	139	124
22	259	196	134	187	244	288	321	326	321	249	192	201
23	278	254	230	230	240	249	254	259	259	206	163	163
24	168	163	163	158	158	148	134	115	124	100	086	091
25	206	230	230	230	235	249	225	225	211	144	110	115
26	115	115	120	120	120	129	139	139	134	048	(—)005	019
27	249	196	163	153	168	168	172	129	072	028	028	033
28	(—)226	(—)039	(—)068	(—)024	(—)015	014	(—)005	014	028	(—)048	(—)111	(—)087
29	206	177	201	216	225	240	225	206	182	124	100	086
30	139	134	134	163	177	196	206	201	196	182	192	206
31	244	240	240	240	235	244	249	249	240	177	144	110
Mean ..	236	230	228	262	246	251	258	251	238	216	177	172

force, March, 1889.

added to .581000 dyne, give the vertical force in C. G. S. units.

.581000+

Day.	P. M.												Mean.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
1	191	254	284	294	271	257	263	278	303	284	281	271	232
2	132	157	153	197	202	242	257	257	253	250	230	236	216
3	217	228	267	287	288	279	299	304	305	306	312	297	226
4	235	212	223	228	234	230	235	255	261	276	282	258	260
5	297	336	313	284	295	305	316	330	384	428	429	381	302
6	295	344	384	374	370	357	358	377	373	355	342	323	298
7	294	310	354	359	374	370	371	386	391	407	408	393	325
8	303	337	362	333	349	350	360	351	357	353	359	354	360
9	253	259	270	284	300	296	306	330	341	347	348	348	317
10	295	325	336	302	308	309	310	320	335	336	347	342	333
11	333	329	315	311	307	308	318	357	367	383	355	321	342
12	202	227	242	276	301	331	317	288	270	262	258	248	286
13	201	230	270	327	324	334	330	378	427	337	338	357	251
14	295	292	259	259	284	290	281	267	258	269	260	246	280
15	261	262	272	282	283	284	294	304	300	316	297	254	282
16	221	222	228	252	243	249	250	264	261	257	263	301	256
17	100	158	222	260	434	757	690	762	610	529	429	314	325
18	204	196	206	206	212	227	200	195	201	226	179	198	221
19	126	137	133	181	206	221	237	251	262	253	254	245	209
20	173	188	233	257	291	292	293	284	280	290	291	287	257
21	134	153	192	216	249	268	278	292	297	302	307	302	238
22	259	278	307	331	364	360	355	350	336	326	312	288	283
23	177	192	206	211	187	192	158	158	153	158	168	168	205
24	139	172	177	196	211	182	240	201	216	230	244	230	165
25	153	148	134	134	139	134	115	120	115	115	115	120	165
26	067	072	096	076	096	110	110	129	124	144	......	....	101
27	024	033	038	048	057	086	067	081	091	100	000	(—)125	086
28	110	168	321	244	244	249	240	283	230	225	220	220	091
29	129	153	168	177	192	196	182	177	177	177	177	144	177
30	249	216	225	192	211	249	249	235	254	264	273	268	209
31	100	086	139	196	216	211	201	187	187	177	172	163	194
Mean ..	199	215	236	244	259	275	274	283	282	280	275	258	243

Regarding the means of H, D, V, it should be remarked that those given in the report for H and V were adopted unchanged, but since took the means out for D, I had the opportunity to reject a few of the outstanding disturbance ordinates, and it would be better to do likewise in the cases of H and V. The original means for D were derived from measures on the composite curves, but it is now thought best not to continue that system of treating the observations.

The result of this computation is not very instructive on the face of of it, because it represents the integrated deflecting force arising from the change in the permanent magnetism of the earth at Washington for 1889, and the periodic term arising from the motion of the earth around the sun. As soon as the secular variation can be discovered by itself, or on the other hand the annual deflection obtained by itself, then the other term can be treated, a process which it may be hoped can be accomplished in due time.

TABLE IV.—*The annual deflection curve for the year 1889.*

Month.	H	D	V	ΔH	ΔD	ΔV	*dx*	*dy*	*dz*	σ	*s*	α	β
		° ′			′							°	°
January..........	.198934	3 59.24	.581789	+221	−1.71	+1337	+221	−99	+1337	244	1354	+80	336
February.........	.198827	3 59.96	.581374	+114	−0.99	+ 922	+114	−58	+ 922	129	931	+83	334
March..............	.198769	4 0.60	.581243	+ 56	−0.35	+ 741	+ 56	−20	+ 791	60	794	+85	340
April...............	.198740	4 1.51	.580913	+ 27	+0.56	+ 461	+ 27	+33	+ 461	43	463	+86	49
May...............	.198678	4 1.60	.580521	− 35	+0.65	+ 69	− 35	+38	+ 69	53	87	+53	132
June...............	.198638	4 0.75	.580134	− 75	−0.20	− 318	− 75	−12	− 318	75	327	−76	189
July...............	.198605	4 0.64	.579532	−108	−0.31	− 920	−108	−18	− 920	110	927	−83	190
August...........	.198745	4 1.35	.579860	+ 32	+0.40	− 592	+ 32	+23	− 592	38	593	−87	34
September........	.198655	4 1.68	.579927	− 58	+0.73	− 525	− 58	+42	− 525	72	530	−83	145
October............	.198655	4 1.04	.580231	− 58	+0.09	− 221	− 58	+ 5	− 221	59	230	−75	175
November........	.198630	4 1.24	.579723	− 83	+0.29	− 729	− 83	+17	− 729	85	734	−83	168
December.........	.198678	4 1.83	.580174	− 35	+0.88	− 278	− 35	+51	− 278	62	285	−77	125
	.198713	4 0.95	.580452										

TABLE V.—*The diurnal deflecting curve for the month of March*, 1889.

	H	D	V	ΔH	ΔD	ΔV	*dx*	*dy*	*dz*	σ	*s*	*a*	β
		° ′ 2 51. 52			′							°	°
Midnight ...	. 198784	+ 68. 57	. 581258	+ 15	—0. 51	+15	+ 15	— 30	+15	34	36	+23	297
1	783	68. 27	236	+ 14	—0. 81	— 7	+ 14	— 47	— 7	50	51	— 8	286
2	803	68. 70	230	+ 34	—0. 38	—13	+ 34	— 22	—13	39	41	—15	327
3	785	68. 36	228	+ 16	—0. 72	—15	+ 16	— 41	—15	44	46	—18	292
4	800	68. 05	262	+ 31	—1. 03	+20	+ 31	— 60	+20	67	70	+16	297
5	811	68. 00	246	+ 42	—1. 08	+ 3	+ 42	— 63	+ 3	76	76	+ 2	303
6	805	68. 13	251	+ 36	—0. 95	+ 8	+ 36	— 55	+ 8	66	67	+ 7	304
7	807	67. 29	258	+ 38	—1. 79	+13	+ 38	—104	+13	111	112	+ 6	291
8	768	66. 30	251	— 1	—2. 78	+ 8	— 1	—161	+ 8	161	162	+ 3	269
9	712	66. 06	238	— 57	—3. 02	— 5	— 57	—174	— 5	183	183	— 2	252
10	663	66. 84	216	—106	—2. 24	—27	—106	—130	—27	168	172	— 9	232
11	679	68. 92	177	— 90	—0. 16	—66	— 90	— 9	—66	91	113	—36	186
Noon	670	70. 74	172	— 99	+1. 66	—71	— 99	+ 96	—71	138	156	—28	186
1	726	72. 25	199	— 43	+3. 17	—44	— 43	+183	—44	187	193	—13	103
2	756	72. 30	215	— 13	+3. 22	—28	— 13	+186	—28	187	191	— 9	94
3	808	72. 24	236	+ 39	+3. 16	— 7	+ 39	+183	— 7	188	189	— 2	78
4	816	71. 34	244	+ 47	+2. 26	+ 1	+ 47	+131	+ 1	140	140	+ 1	70
5	808	70. 32	259	+ 39	+1. 24	+16	+ 39	+ 72	+16	81	83	+12	61
6	770	69. 78	275	+ 1	+0. 70	+32	+ 1	+ 40	+32	40	52	+38	91
7	784	69. 40	274	+ 15	+0. 32	+31	+ 15	+ 18	+31	25	40	+52	58
8	788	68. 94	283	+ 19	—0. 14	+40	+ 19	— 8	+40	21	46	+62	339
9	785	68. 97	282	+ 16	—0. 11	+49	+ 16	— 7	+49	18	53	+70	340
10	769	68. 20	280	0	—0. 88	+37	0	— 51	+37	51	63	+36	269
11	786	68. 46	275	+ 17	—0. 62	+32	+ 17	— 36	+32	40	51	+39	296
Midnight ...	784	68. 57	258	+ 15	—0. 51	+15	+ 15	— 30	+15	34	36	+23	297
	. 198769	69. 08	. 581243										

IV.—MODEL SHOWING THE DIURNAL DEFLECTIONS.

In order to bring out visibly the meaning of our results s, α, β, we constructed a model in the following way. A rubber ball about 10 inches in diameter is surrounded by meridian lines, one for each hour. Instead of revolving the ball upon its axis, the magnetic system is supposed to take up its place from meridian to meridian, according to the local hour angle of the station, referred to the sun. A series of pins is inserted at the proper angles α, β, and if the force is acting downwards beneath the plane of the horizon the head is left on, and if above the plane of the horizon the pin head is removed, thus indicating the meaning of plus and minus α. The result shows that the ball is a conductor, that the forces enter upon the dark side of the earth and depart on the light side in the northern hemisphere, thus acting toward the sun, but the symmetrical plane of the field, as shown by the points of tangency and the inclination of the forces, is turned from the meridian supposed to represent the sun, so that a station reaches this plane before arriving at the meridian of the sun. We expect to explore this field of research fully, and only indicate the processes in this connection.

A few specimen results for a series of stations in June, 1883, are added to further illustrate this subject. After a study of the polar stations, bearing in mind the angles that the poles (ecliptic, geographical, magnetic) and the zenith of the various stations bear to each other, it will be seen that the action of a polarized conductor rotating in the field of the radiant sunlight regarded as a uniform magnetic field of force, is sufficient to explain clearly the variety of results that have been deduced. Instead of giving the magnetic azimuth β, the geographical azimuth is taken, A, counted from the north through the west.

TABLE VI.—*Stations with the diurnal deflecting forces that were in action during the month of June*, 1883.

Hours.	Fort Rae.				Point Barrow.				Kingua Fjord.				Jan-Mayen.				Bossekop.			
	σ	s	a	A	σ	s	a	A	σ	s	a	A	σ	s	a	A	σ	s	a	A
			°	°			°	°			°	°			°	°			°	°
Midnight......	49	50	—11	94	47	47	0	59	49	54	+25	49	63	65	+14	204	82	101	—36	169
2..............	47	78	+53	104	40	55	+43	94	46	58	+37	22	105	109	+15	226	90	116	—39	160
4..............	59	122	+61	152	58	97	+53	154	52	77	+48	346	127	129	— 9	241	51	78	—49	142
6..............	101	131	+39	179	116	155	+41	187	68	114	+53	302	94	116	—36	250	31	41	—40	122
8..............	115	116	+ 7	192	131	148	+24	201	97	129	+41	274	83	73	—63	259	19	26	—42	187
10..............	52	58	—26	219	62	63	—10	195	100	101	+ 7	267	14	62	—77	300	14	17	—34	203
Noon	15	32	—62	283	19	40	—62	101	73	107	—47	347	46	79	—54	30	26	29	+26	291
2..............	45	47	—17	346	30	46	—49	38	63	123	—59	176	95	121	—47	40	57	79	+44	336
4..............	90	94	—17	343	54	65	—34	12	78	122	—51	146	137	172	—37	43	80	118	+47	346
6..............	106	118	—26	344	79	90	—28	351	78	94	—34	122	98	163	—52	58	87	122	+44	347
8..............	72	92	—38	349	86	105	—35	340	87	88	+ 8	95	63	128	—60	116	55	68	+36	339
10..............	34	63	—57	64	68	76	—34	3	76	77	+ 8	72	52	75	—46	169	28	33	—46	186
Midnight......	49	50	—11	94	47	47	0	59	49	54	+25	49	63	65	+14	204	82	101	—36	169

TABLE VI.—*Stations with the diurnal deflecting forces that were in action during the month of June*, 1883—Continued.

Hours.	Wilhelmshaven.				Pawlowsk.				Vienna.				Tiflis.				Zi-ka-wei.			
	σ	*s*	*a*	A	*σ*	*s*	*a*	A	*σ*	*s*	*a*	A	*σ*	*s*	*a*	A	*σ*	*s*	*a*	A
			°	°			°	°			°	°			°	°			°	°
Midnight...	8	13	+52	330	8	10	- 38	338	9	9	+ 8	329	7	8	+29	314	14	14	+11	11
2...	6	7	+17	318	9	10	−40	292	10	11	+16	333	·8	8	+22	292	20	21	+17	353
4...	16	17	+14	287	16	17	−16	282	13	14	+16	316	10	11	+22	298	35	36	+14	353
6...	32	32	+ 4	265	28	29	−11	265	29	30	+13	314	30	31	+11	271	50	53	+20	334
8...	30	33	−21	231	35	35	− 6	230	25	25	0	247	33	34	0	246	40	40	0	279
10...	34	38	−26	190	29	30	−11	191	23	25	−24	174	18	21	−31	189	25	36	−46	217
Noon.......	36	48	−40	144	35	36	−11	134	30	35	−30	130	28	31	−26	89	23	34	−46	95
2...	36	50	−44	108	33	33	+ 4	98	35	36	−11	106	36	37	−12	76	34	·36	−18	73
4...	24	25	+14	68	25	28	+26	51	21	21	+10	94	21	21	0	83	21	21	+15	121
6...	23	35	+50	24	20	25	+37	16	6	11	+56	20	5	10	+61	36	56	56	+ 6	180
8...	26	38	+47	358	19	21	+25	4	10	12	+31	359	2	6	+71	357	22	23	+17	174
10...	16	30	+59	351	14	14	− 7	356	13	13	+14	251	6	8	+39	341	11	11	+15	160
Midnight...	8	13	+52	330	8	10	−38	338	9	9	+ 8	329	7	8	+29	314	14	14	+11	11

We now pass to a table showing the method of comparing the magnetic with the meteorological elements.

TABLE VII.—*The meteorological deflections for the month of March,* 1889.

Date.	H	D	V	ΔH	ΔD	ΔV	dx	dy	dz	σ	s	α	β	D
		° ′			′							°	°	
		2 51.52												
1....	.198675	+70.01	.581232	− 94	+0.93	− 11	−123	+72	− 77	141	159	−28	150	
2....	731	69.39	216	− 38	+0.31	− 27	− 65	+35	− 89	73	115	−51	152	
3....	780	69.38	226	+ 11	+0.30	− 17	− 14	+34	− 75	35	82	−75	113	
4....	852	68.71	260	+ 83	−0.37	+ 17	+ 60	− 7	− 37	59	70	−31	352	
5....	836	68.44	302	+ 57	−0.64	+ 59	+ 36	−23	+ 9	42	43	+12	328	D_3
6....	727	69.69	298	− 42	+0.61	+ 55	− 61	+48	+ 10	77	77	+ 7	141	D_3
7....	733	68.75	325	− 36	−0.33	+ 82	− 53	− 8	+ 41	54	66	+36	190	D_1
8....	796	69.40	360	+ 27	+0.32	+117	+ 12	+29	+ 80	31	85	+69	69	
9....	796	69.32	317	+ 27	+0.24	+ 74	+ 13	+23	+ 41	25	47	+58	60	
10....	813	69.07	333	+ 44	−0.01	+ 90	+ 32	+ 8	+ 61	33	68	+62	15	
11....	861	69.14	342	+ 92	+0.06	+ 99	+ 82	+11	+ 75	82	109	+43	7	
12....	887	68.44	286	+118	−0.64	+ 43	+110	−31	+ 23	115	117	+10	344	D_2
13....	774	69.61	251	+ 5	+0.53	+ 8	− 1	+36	− 7	36	36	−10	91	D_2
14....	783	69.25	280	+ 14	+0.17	+ 37	+ 10	+14	+ 27	17	32	+56	55	
15....	809	69.05	282	+ 40	−0.03	+ 39	+ 38	+ 1	+ 39	38	55	+45	2	
16....	829	69.13	256	+ 60	+0.05	+ 13	+ 60	+ 4	+ 18	60	62	+17	2	
17....	658	69.32	325	−111	+0.24	+ 82	−110	+13	+ 97	111	153	+44	174	D_4
18....	702	68.06	221	+ 33	−0.42	− 22	+ 35	−28	+ 3	44	44	+ 2	320	
19....	783	68.56	209	+ 14	−0.52	− 34	+ 17	−35	+ 1	39	39	+ 2	293	
20....	747	69.15	257	− 22	+0.07	+ 14	− 18	− 3	+ 69	19	71	+74	184	
21....	775	69.84	238	+ 6	+0.76	− 5	+ 11	+36	+ 50	37	61	+54	73	
22....	722	68.33	283	− 47	−0.75	+ 40	− 41	−54	+105	07	124	+57	232	D_2
23....	793	68.92	205	+ 24	−0.16	− 38	− 31	−20	+ 37	36	52	+42	213	D_2
24....	800	69.44	165	+ 31	+0.36	− 78	+ 39	+ 7	+ 7	40	40	+10	11	
25....	781	68.82	165	+ 12	−0.26	− 78	+ 21	−31	+ 17	37	41	+24	304	
26....	806	68.77	101	+ 37	−0.31	−142	+ 47	−36	− 37	58	68	−32	322	
27....	787	68.55	086	+ 18	−0.53	−157	+ 28	−50	− 42	58	71	−45	300	D_3
28....	644	68.68	091	−125	−0.40	−152	−113	−44	− 37	120	125	−17	202	D_3
29....	705	69.35	177	− 64	+0.27	− 66	− 51	− 7	+ 69	52	85	+54	190	D_1
30....	711	68.63	209	− 58	−0.45	− 34	− 44	−50	+111	66	128	+59	229	
31....	764	69.53	194	− 5	+0.45	− 49	+ 10	0	+106	10	106	+85	0	
	.198769	69.08	.581243											

TABLE VIII.—*The meteorological elements for the month of March*, 1889.

Date.	Barometer.	Thermometer.	Relative humidity.	Rain.	Clouds.	Wind.		Magnetic azimuth of the isobars.		
						Direction.	Force.	8 a. m.	8 p. m.	Mean.
	Inches.	°	*Per cent.*	*Inches.*						
1..	30.48	37.0	81	....	9	ne., w., se.	1	160	142	151
2..	30.26	39.5	86	0.17	10	se.	2	148	150	149
3..	29.99	40.5	92	0.88	10	s., ne., n.	4	112	120	116
4..	29.74	39.5	92	0.86	10	n.	8–12	345	350	348
5..	29.72	41.0	81	....	10	nw.	14	326	342	334
6..	29.54	41.5	56	....	2	nw.	13	180	188	184
7..	29.49	40.5	66	....	4	nw.	8	210	190	200
	.....	....	..							
8..	29.67	38.3	59	....	2	nw.	9	40	40	40
9..	29.86	35.4	70	....	6	nw.	14	40	30	35
10..	29.96	34.8	68	....	9	nw.	12	15	10	12
11..	30.10	38.3	56	....	2	nw.	11	6	245	6–245
12..	30.09	44.5	61	....	0	nw., se.	1–3	290	310	300
13..	30.06	50.0	66	....	4	nw., se.	4	95	84	90
	.....	....	..							
14..	30.15	47.1	72	....	9	ne.	10	60	44	52
15..	30.01	41.9	64	....	10	ne.	12	30	320	355
16..	29.88	44.5	70	....	10	ne., n., nw.	8	330	20	355
17..	29.87	51.3	60	....	5	nw., ne.	3	170	140	155
18..	29.90	47.5	76	0.21	6	nw., se.	3	330	310	320
19..	29.76	42.0	94	2.23	10	ne.	8	230	280	255
20..	29.76	40.0	83	1.00	10	ne.	10	295	130	212
21..	29.78	36.0	91	0.28	10	nw.	6	165	188	177
	.....	....	..							
22..	30.17	44.0	70	....	9	nw.	6	225	210	218
23..	30.18	48.5	68	....	6	nw.	5	200	225	213
24..	29.94	52.3	64	....	7	nw., sw.	3	20	15	17
25..	29.67	52.0	77	....	10	n., se.	3	300	310	305
	.....	....	..							
26..	30.05	41.2	57	....	1	se.	4	320	320	320
27..	29.94	53.3	74	0.03	4	se.	5	300	270	285
28..	29.90	45.0	65	0.03	9	sw., nw.	2–10	180	200	190
29..	30.07	47.7	54	....	2	nw., sw.	3–10	260	160	210
	.....	....	..							
30..	30.35	36.0	60	....	0	nw.	13	210	00	210–0
31..	30.09	50.7	78	....	10	s.	12	350	350	350

The H, D, V are copied from the daily means for the month of March. ΔH, ΔD, ΔV are obtained by subtracting the mean value of the month from these daily means. The dx, dy, dz are derived from ΔH, ΔD, ΔV by applying the correction for the annual curve in the following manner: Since the mean for the month may be taken as the correct value of the H, D, V, for the middle of the month, by subtracting these monthly means in succession we obtain remainders to be distributed along the interval, in proportion to the time, the only error being in the assumption that the second difference may be neglected. Thus we have for the intervals:

Intervals.	H	D	V
February and March	—58	+0.64	—131
March and April	—29	+0.91	—330

Half of these quantities are to be distributed from the beginning of the month, with the same sign forwards and with the opposite sign backwards, reducing them to zero by the middle of the respective months. Since ΔD is in minutes of arc it must be reduced to force, as explained above; σ, s, α, β are taken from the diagram scale. D_n represents the disturbance as noted on the photographic curves, D_1 indicating a mild disturbance, and D_4, the most severe found.

The meteorological elements are taken from the records of the U. S. Naval Observatory, by the permission of Professor J. R. Eastman, these numbers being the mean of eight three-hourly readings. The barometer and thermometer are also compared with the means of the barograph and the thermograph of the U. S. Weather Bureau, which is in the neighborhood, as a check. As all our work is purely differential, there is no need to pay special attention to absolute values in the magnetic or in the meteorological records, the relative changes alone being important.

The magnetic azimuth of the isobars is scaled off from the weather maps of the U. S. Signal Service for the month. It is only fair to remark that in reducing the azimuth to two readings for 8 a. m. and 8 p. m., we are comparing the mean magnetic azimuth β of a whole day with the mean of these two readings. A far better appreciation of the relation will be obtained by plotting the value of β upon the map itself, where it will be seen in its general relation to the whole set of isobars, and to the prevailing pressures about the highs and the lows. The comparison here indicated has been extended during each month for the three successive years 1889, 1890, 1891, and the persistence with which the relative changes follow each other in time precludes the possibility that the agreement is accidental.

At this time we refrain from discussing the meaning of these facts, because there are many physical conditions and relations involved which are not yet understood. It is seen by an attentive inspection of the variations in the columns σ, s, a, β, that there are specially marked breaks in one or more of the terms, indicating a change in some of the magnetic stresses; in the same manner the barometer, thermometer, and relative humidity seem to vary rapidly in the same neighborhood, the commonest form being when the barometer reverses from falling to rising, the thermometer changes suddenly, and the relative humidity diminishes. Such breaks are indicated for the month of March by some dotted lines.

It will be observed that there is a decided tendency for the magnetic change to precede the meteorological by about one day, as if the magnetic influence being more sensitive felt the change before it came. It will also be noted that this magnetic change seems to occur when the rain center, which precedes the low barometer by several hours, is near at hand, or at least to be intimately related to that critical state of the atmosphere. Such a comparison as is here exhibited for March, 1889, has been carried out in full for the three years 1889–1891, and the number of coincidences, as well as the anticipatory relationship of the two sets of phenomena, persist throughout this period. It is intended to extend such a comparison to European magnetic and meteorological stations as rapidly as possible.

This comparison has been followed into its details by constructing a large monthly diagram of all the curves mentioned—humidity, barometer, thermometer, with appended data for the rain, clouds, and wind, also the declination, horizontal force, and vertical force. The meteorological curves are copied from self-registering instrument traces, and the magnetic curves from the traces given by the Kew instruments of the U. S. Magnetic Observatory, the two sets of apparatus being about 150 feet apart. All the traces are reduced to the same scale, four centimeters daily, the vertical ordinates being adapted to give clearly the relative changes on a similar vertical scale as seen by the eye. The points of the six-hour ordinates are plotted, also all the maxima and minima. A single sheet contains the continuous curves for a month. The traces for H and V were not corrected for temperature during October and November, but this correction has been applied to all that follow. Now a mean line is drawn through a series of middle points, counting successive maxima and minima points as the extremes for determining the mid-points, each curve thus having its mean curve.

If the month is blocked off into parts determined, for instance, by the intervals from one low to the next low, it is seen that both the meteorological and the magnetic mean curves tend to sway up and down once, that is, have but one inflection between such limits, and that the intensity of the meteorological conditions is responded to by the magnetic conditions. Furthermore, the amplitude of each of the magnetic traces rises and falls once during the interval indicated, showing that the passage of an atmospheric wave over a station is attended by an intensification and a relaxation of the magnetic deflecting forces.

DISTRIBUTION OF THE DEFLECTIONS.

We are thus brought to describe a device of interest, namely, a method for distributing the mean meteorological magnetic results just used in computation over the whole of the day, so as to obtain the meteorological effect at any given hour, freed from the diurnal and the disturbance effects. The question is, to what shall the photographic trace, with all its irregularities, be referred, in order at any given moment to measure out the meteorological residual. These traces sway up and down, as a whole, relatively to the base line, apart from the gradual change produced by loss of magnetism of the magnet, and from the changes in the coefficients by the temperature. The residuals ΔH, ΔD, ΔV, as derived from the printed page, being freed by computation from these sources of change, still represent that meteorological change as a mean value, but what we want is the twenty-four terms of which it is the arithmetical sum.

Our process is as follows:

The traces of the magnetic instruments of the Washington Observatory are so arranged that when looking at the curve as developed from left to right, beginning at about 12 o'clock noon and ending at the next 12 o'clock noon, in the H and D the base line is below the trace, but in V it is above the trace. The introduction to the volume, page 5, gives +1 millimeter ordinate = + .000048 C. G. S. units for H. F; +1 millimeter ordinate = +1'.13 westerly declination; and +1 millimeter ordinate = —.000048 C. G. S. units for V. F. Hence, laying the traces before us from left to right, in all cases of residual ordinates measured from the curve itself, above the curve means a positive change or increase in force, and below the curve a negative change or decrease in force.

We have constructed sets of normal scales for each month to facilitate our measurements. The material on which they are made is sheet celluloid, glazed on one side and rough on the other, the latter being peculiarly favorable for marking with common ink. The celluloid is cut in strips somewhat longer than the daily traces, scratched with three parallel lines two millimeters apart, there being three such groups, one for each of the H, D, V residuals. Upon these groups, counting from the middle line, is plotted, one for each hour at the proper distances corresponding to the automatic time breaks in the base line, the value of the residuals for the several hours, all in terms of millimeters. That is, the values of ΔH, ΔD, ΔV, as given in the computation of the diurnal deflecting curve, are changed to millimeters and rearranged in the following order:

Afternoon—March, 1889.

	12	1	2	3	4	5	6	7	8	9	10	11	12
H.....	−2.0	− .9	− .3	+ .8	+1.0	+ .8	− .1	+ .3	+ .4	+ .3	− .1	+ .4	+ .3
D.....	+1.7	+3.2	+3.2	+3.2	+2.3	+1.2	+ .7	+ .3	− .1	− .1	− .9	− .6	− .5
V.....	−1.4	− .9	− .6	− .1	0	+ .3	+ .6	+ .6	+ .8	+1.0	+ .9	+ .6	+ .3

Forenoon—March, 1889.

	12	1	2	3	4	5	6	7	8	9	10	11	12
H.....	+ .3	+ .3	+ .7	+ .3	+ .6	+ .8	+ .7	+ .8	0	−1.2	−2.1	−1.8	−2.0
D.....	− .5	− .8	− .4	− .7	−1.0	−1.1	− .9	−1.8	−2.8	−3.0	−2.2	− .2	−1.7
V.....	+ .3	− .1	− .3	− .3	+ .4	+ .1	+ .2	+ .3	+ .2	− .1	− .6	−1.3	−1.4

The resulting scale for March consists, therefore, of a succession of dots one hour apart, following the normal diurnal curve of the month in H, D, V. A second scale is copied from the first by dotting in the points as superposed, only in the second scale the parallel lines are omitted.

Having thus obtained the normal scale, the problem is to apply it to any day of the month. This scale is most accurate for the middle of the month. If another be formed for the adjacent months, February and April, these will differ a little from the scale for March, by as much as the diurnal curve of one month deviates, from its neighbor, and evidently, by proportion, a series of scales can be formed of accurate application to any given day. This would be too great a refinement for our purpose just now, and we use the March scale throughout the month. If the curve for any day were unaffected by causes other than those which produce the diurnal curve, then the trace would agree closely with the curve just constructed. But wishing to eliminate this ideal curve from the annual, the meteorological, and the disturbance deflections, our method is as follows:

Corresponding to any given hour for each day of the month, according to the printed page, there is a computed value of absolute measure in H, D, V to which that ordinate corresponds. If from the final means of the month (in the corner of the pages) a value of the annual curve be computed by plotting on a diagram and reading off the values for the intermediate dates, and then to each of these values, one for each day, the mean diurnal values for the month be added, the normal diurnal values for that day are obtained, that is, those several values which the undeflected daily traces should have read. By subtracting the actual readings as printed, from these values as computed, we obtain residual corrections to the traces to find the normal diurnal curve. Thus we can plot down normal points on the trace sheets, and then by applying the scales to a few of these points, say three for each day, the true normal position of the undeflected trace stands before us, with which the actual trace can immediately be compared. For example, here is given the complete computation for H and the results of similiar processes for D and V:

TABLE IX.—*Deflection differences from the traces to the normal diurnal curves H, D, V.*

Date.	Annual H.	12 o'clock noon.	Residual.	Corrected value.	Difference.	12 o'clock midnight.	Residual.	Corrected value.	Difference.	H		D		V	
										12 noon.	12 midnight.	12 noon.	12 midnight.	12 noon.	12 midnight.
1..........	.198795	.198670	−99	.198696	− 26	.198729	+15	.198810	− 81	− .5	−1.6	− .2	+ .8	−3.1	−1.5
2..........	793	605		694	− 89	787		808	− 21	−1.8	− .4	+ .4	+ .7	−2.7	−2.1
3..........	791	611		692	− 81	845		806	+ 39	−1.6	+ .8	− .3	+1.8	−2.8	− .8
4..........	789	805		690	+115	921		804	+117	+2.3	+2.4	0	+ .1	+ .1	−1.4
5..........	787	890		688	+202	658		802	−144	+4.1	−2.9	− .9	−2.5	0	+1.1
6..........	784	652		685	− 33	594		799	−205	− .7	−4.1	[+5.7]	−4.1	+ .6	+ .1
7..........	782	611		683	− 72	755		797	− 42	−1.5	− .8	−1.1	+ .2	+ .9	+1.8
8..........	781	649		682	− 33	793		796	− 3	− .7	− .1	+1.6	+ .5	+ .9	+ .9
9..........	780	683		681	+ 2	851		795	+ 56	0	+1.1	+ .5	+ .6	0	+ .9
10..........	778	651		679	− 28	838		793	+ 45	− .6	+ .9	− .5	+ .1	+ .8	+1.0
11..........	777	713		678	+ 35	866		792	+ 74	+ .7	+1.5	+ .2	− .1	+2.4	+ .8
12..........	776	752		677	+ 75	849		791	+ 58	+1.5	+1.2	− .7	− .1	0	− .5
13..........	774	833		675	+158	624		789	−165	+3.2	−3.3	−1.5	+ .3	− .1	+1.8
14..........	772	684		673	+ 11	889		787	+102	+ .2	+2.1	+ .7	− .2	+3.0	− .2
15..........	771	679		652	+ 7	828		786	+ 42	+ .1	+ .9	+ .2	− .8	+1.6	+ .1
16..........	770	669		671	− 2	895		785	+110	0	+2.2	+ .8	− .1	+1.4	+1.2
17..........	769	825		670	+155	595		784	−189	+3.1	−3.8	+ .9	−4.8	− .6	+1.6
18..........	768	....		669	[−101]	789		783	+ 6	[−3.7]	+ .1	+ .9	−1.3	+ .2	− .5
19..........	767	691		668	+ 23	804		782	+ 22	+ .5	+ .5	− .9	+ .4	+ .3	+ .6
20..........	766	655		667	− 12	753		781	− 28	− .2	− .6	− .9	+ .4	+1.7	+1.6
21..........	765	552		666	−114	905		780	+125	−2.3	+2.5	+1.2	+ .3	+ .2	+2.0
22..........	764	581		665	− 84	793		779	+ 14	−1.7	+ .3	+ .8	+ .1	+1.9	+1.9
23..........	762	761		663	+ 98	784		777	+ 7	+2.0	+ .2	−1.1	0	+1.2	− .4
24..........	761	649		662	− 13	842		776	+ 66	− .3	+1.3	− .1	+2.3	− .1	+1.0
25..........	760	697		661	+ 36	824		775	+ 49	+ .7	+1.0	− .2	+ .2	+ .5	−1.1
26..........	759	750		660	+ 90	....		774	[− 58]	+1.8	[−1.2]	+1.2	[0]	−1.2	[− .9]
27..........	759	793		660	+133	643		774	−131	+2.7	−2.6	+ .1	−3.1	− .7	−5.6
28..........	758	498		659	−161	625		773	−148	−3.2	−3.0	+4.1	− .3	−2.9	+1.5
29..........	757	368		658	−290	847		772	+ 75	−5.8	+1.5	+3.5	− .5	+ .7	+ .2
30..........	756	509		657	−148	806		771	+ 35	−3.0	+ .7	−2.1	+ .3	+3.4	+2.9
31..........	756	628		657	− 29	797		771	+ 26	− .6	+ .5	+ .5	+ .2	+1.6	+1.0

The column "annual H" gives the value of the horizontal force for March as taken from the plotted curve; 12 o'clock noon and 12 o'clock midnight are copied from the absolute values of H for these hours; "residual" means the ordinate of the diurnal deflection curve for the respective hours, and it is applied as a correction to annual H to give the "corrected value;" the "difference" is obtained by subtracting the "corrected value" from the "12 o'clock" readings; under H, D, V occur the corresponding residual ordinates in millimeters. Similar residuals can be found for any other hours; where bracketed values occur, the next preceding hour was taken, in case the 12 o'clock values are missing for any reason.

The curves on the sheets are next gone over, and dots are placed above or below the magnetic trace to show for at least three points each day where the normal curve ought to have been located, and by matching these points and the corresponding points on the scale we see the relation between the given curve and the theoretical curve. Having thus practically eliminated the annual and the diurnal deflections, what remains is to be attributed to the meteorological and the disturbance deflections. It is seen, (1) that the daily curves tend to sway up and down on either side of the theoretical curve, this being the meteorological effect, (2) that the disturbances are superposed upon the meteorological trace; hence these are to be separated.

The second dotted scale is taken, disregarding now all our previous processes, and it is laid upon the daily trace so as to match as perfectly as possible its course throughout the day, this on some days being a simple matter. The position of this scale is indicated by dashes at each end of the day, and evidently the dashes will be separated from the dots set there by the previous work, according to the trend of the curve. The end dash of one day is transferred to the beginning of the following day, at the same distance from its dot, and this forms the starting point or pivot for one end of the scale, which has to be swung upon the day's curve by best judgment.

In this way each day's dashes are made to depend mutually upon the preceding and the following day, as well as upon the curve itself, and it is surprising how much accuracy of setting the scale can be attained in spite of the many irregularities of the curve, because there are in the course of the three days certain parts which are normal so far as the disturbances are concerned. We take the liberty of recommending this treatment of observations, because it goes to the bottom of the matter, at least so far as the specific disturbances are concerned.

Next, the two scales are set simultaneously over the dots and the dashes, and, being transparent, the curve and the two sets of dots on the scales can be seen all together. By reading off the differences between the two sets of dots or the first normal dots and the curve itself, when the curve runs closely to the dots of the second scale, we have the meteorological residual ordinates by themselves, freed from the annual, the diurnal, and the disturbance residuals. Thus have we distributed throughout the day the meteorological mean residuals which have already been used.

Short example of meteorological residuals between two scales.

AFTERNOON.

March.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Midnight.
1 ……	−2.3	−2.2	−2.1	−2.0	−1.9	−1.8	−1.7	−1.5	−1.3	−1.2	−1.0	−0.9	−0.7
2 ……	+1.0	+0.9	+0.8	+0.7	+0.5	+0.3	+0.2	+0.1	0.0	0.0	−0.1	−0.1	−0.1
3 ……	−1.2	−1.2	−1.0	−0.8	−0.6	−0.4	−0.2	0.0	+0.2	+0.4	+0.6	+0.8	+1.0
4 ……	+3.4	+3.3	+3.2	+3.1	+3.0	+2.9	+2.8	+2.8	+2.8	+2.7	+2.7	+2.7	+2.7
5 ……	+2.5	+2.4	+2.2	+2.0	+1.9	+1.8	+1.7	+1.6	+1.5	+1.3	+1.1	+1.0	+0.9

FORENOON.

March.	Midnight.	1.	2.	3.	4.	5.	6.	7.	7.	9.	10.	11.	Noon.
1 ……	−0.7	−0.5	−0.3	−0.1	0.0	0.0	+0.2	+0.3	+0.4	+0.6	+0.8	+0.9	+1.0
2 ……	−0.1	−0.2	−0.2	−0.2	−0.3	−0.4	−0.5	−0.7	−0.9	−1.0	−1.1	−1.1	−1.1
3 ……	+1.0	+1.2	+1.4	+1.6	+1.8	+2.0	+2.2	+2.4	+2.6	+2.8	+3.0	+3.2	+3.4
4 ……	+2.7	+2.6	+2.6	+2.6	+2.6	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5
5 ……	+0.9	+0.7	+0.5	+0.3	+0.1	0.0	0.0	−0.1	−0.2	−0.3	−0.4	−0.5	−0.6

By careful management of these scales there can be made a very useful set of reference curves, from which even minute studies into the changes that are continuously going on can be prosecuted, and as these are deflecting forces depending upon existing physical conditions, it will assist greatly in the solution of all the allied problems.

ORIGIN OF THE DISTURBANCES.

I can give one striking illustration of this fact in regard to the origin of the disturbances that have been so long under consideration. By matching one dotted scale to the curve, as above suggested, it is seen that on certain days, for several consecutive hours the trace is swept away from the dots in a pronounced manner, during periods of disturbance. Now, measuring off the residual disturbance ordinates, and combining them as in the other cases, we find the s, α, β corresponding to them, that is, the force, and the direction from which it came, that effected the displacement of the curve. Having computed about twenty such periods of disturbance, obtained the coördinates of the deflecting force, transferred them to another ball with pins, it is seen that instead of coming from all quarters in space, they originate in three directions, one perpendicular to the plane of the ecliptic, one towards the sun, and one in the direction of the orbital motion of the earth. These directions are all of them modified, as they should be, for the curvature of the lines of force, as if the earth were an absorbing conductor in uniform fields; and because the earth is rotating in these fields, the radiant and the orbital fields show the accompanying retardation in a complete manner. This distribution may be regarded as a case of magnetic refraction, and as the analytical solution of the conditions is extremely difficult, this may be the best way to secure a practical set of formulæ. Unless further computations produce conflicting evidence, these facts must be taken as testimony of great importance in regard to our general view of the subject in its cosmical relations. An example from each of these three fields is appended. The disturbance residuals are so large, in reference to the margin of doubt in setting the scale (that is, one-half a millimeter), as to admit of no question as to the meaning of the results.

Disturbance of March 17–18, 1889, *originating in the coronal field.*

Hours.	*dx*	*dy*	*dz*	*s*	*a*	*β*	Hours.	*dx*	*dy*	*dz*	*s*	*a*	*β*
					°	°						°	°
3 p. m....	+ 100	+ 23	+ 10	104	+ 4	13	9 p. m...	−900	− 98	+400	990	+24	186
3.30......	+ 200	+ 40	+ 50	212	+14	12	9.30.....	−650	−139	+350	756	+28	192
4.........	+ 450	+ 35	+ 60	432	+ 8	3	10.......	−425	−116	+275	516	+33	195
4.30......	+ 100	+127	+140	194	+41	38	10.30....	−450	00	+200	488	+24	180
5.........	0	+156	+200	254	+52	90	11.......	−390	+116	+210	456	+26	162
5.30......	− 200	−104	+310	370	+57	207	11.30....	−180	+173	+115	276	+26	126
6.........	− 450	−347	+500	828	+47	218	12 a. m...	−325	−266	+ 85	436	+12	219
6.30......	− 525	+104	+550	762	+46	168	12.30....	−350	−197	+ 50	412	+ 6	209
7.........	−1100	+133	+450	1130	+23	173	1........	−175	− 98	+105	228	+27	210
7.30......	− 850	+185	+430	978	+64	108	1.30.....	−185	− 58	+115	228	+31	198
8.........	− 700	+145	+550	912	+37	169	2........	−200	− 47	+275	346	+53	194
8.30......	− 650	− 81	+450	738	+34	187							

Disturbance of April 7–8, 1889, *originating in the orbit field.*

Hours.	*dx*	*dy*	*dz*	*s*	*a*	*β*	Hours.	*dx*	*dy*	*dz*	*s*	*a*	*β*
					°	°						°	°
8 p. m....	+ 30	− 58	+ 10	67	+ 9	297	2 a. m...	+160	− 58	−275	326	−58	340
8.30......	−115	−139	+ 65	192	+20	231	2.30.....	+ 35	−405	−295	504	−36	276
9.........	−300	−278	+ 85	402	+13	222	3........	− 65	−682	−310	750	−24	264
9.30......	−365	−491	+ 75	618	+ 7	234	3.30.....	−240	+260	−285	459	−38	227
10........	−780	−780	+ 30	1108	+ 3	225	4........	− 75	+173	−215	288	−49	114
10.30.....	−670	−434	+ 25	800	+ 3	213	4.30.....	0	+ 12	−155	156	−86	90
11........	−215	−116	+ 90	266	+19	208	5........	− 55	−104	−120	168	−45	242
11.30.....	−200	−289	+ 75	362	+13	235	5.30.....	− 75	− 70	− 45	113	−23	223
12 a. m ...	−135	−129	+110	226	+29	226	6........	− 90	− 58	− 35	113	−18	213
12.30.....	+ 15	− 58	+ 45	77	+35	284	6.30.....	− 20	− 47	− 10	53	−11	247
1.........	− 75	− 35	− 20	85	−13	205	7........	− 75	− 35	− 15	84	−11	205
1.30......	−165	+ 58	−225	288	−52	199							

Disturbance of September 22, 1889, *originating partly in the radiant field.*

Hours.	*dx*	*dy*	*dz*	*s*	*a*	*β*	Hours.	*dx*	*dy*	*dz*	*s*	*a*	*β*
					°	°						°	°
4 a. m....	+ 80	0	− 15	82	−11	0	10 a. m...	−365	+ 23	− 50	372	− 8	176
4.30......	+ 65	− 47	− 10	81	− 7	323	10.30....	−325	+202	− 60	386	− 9	148
5.........	0	−150	− 15	152	− 5	270	11.......	−480	+191	− 65	528	− 7	158
5.30......	− 50	−127	− 20	139	− 8	248	11.30....	−350	+364	− 50	515	− 6	134
6.........	− 15	− 75	− 30	84	−22	258	12 noon..	−100	+116	− 50	162	−18	132
6.30......	−280	+ 87	− 40	298	− 8	163	12.30 p. m	+ 90	+ 37	− 55	138	−24	44
7.........	+250	+341	− 60	428	− 7	54	1........	− 50	+277	− 45	288	− 8	100
7.30......	+270	+ 58	− 60	286	−13	12	1.30.....	−200	+214	− 30	296	− 7	133
8.........	+160	+ 17	− 60	171	−21	6	2........	−140	+116	− 30	368	− 6	140
8.30......	+100	0	− 65	119	−33	0	2.30.....	+160	+133	− 20	45	−26	104
9.........	+140	+156	− 45	223	−23	48	3........	−150	+110	− 10	186	− 3	144
9.30......	+ 50	+ 58	− 35	85	−24	50	3.30.....	−160	+ 93	00	186	0	150

The coronal field is most clearly defined, the direction of the forces being persistent, and the whole field exhibiting activity throughout the twenty-four hours. By introducing this force into the formulæ, already given in previous papers, some knowledge of the originating forces at the surface of the sun may be computed; also by studying these disturbances we shall have a more sensitive guide to the fluctuations of the solar forces than has been gained through observations of the sun spots, faculæ, etc.

The orbital field is more of a mystery. It exists only on the dark side of the earth, and shows some diversity of direction, arising from the fact, probably, that it is a weaker field, which, if originating in induction at the surface of the earth, as is likely, is subject to more conflicting impulses. It is thrown backward about 23° by the rotation of the earth on its axis, and in some parts of it the forces are parallel to each other, even when derived from dates that are months apart.

The radiant field is the least important of the three, and it may not be a true disturbance field of itself, but only a reassertion of the deflections that produce the diurnal variations. At certain local hour angles there is seen a conflict between these different fields, depending upon the relative strength of those in action, and this is evident by the uncertainty of direction among the pins representing these forces. Such hours may be mentioned at 3 p. m.–5 p. m. and 5 a. m.–7 a. m., that is, along the places where the radiant magnetic field falls tangent to the surface of the earth.

On January 5, 1892, there was registered at the Washington Magnetic Observatory the impulses of a strong magnetic disturbance. Upon applying to the traces the analysis and the computations described above, it appeared to exhibit so excellent an example of some of the conclusions stated in this paper that the data and illustrations of it are now given.

The traces of H, D, and V are copied directly from the magnetograph curves. They begin at 12 o'clock noon January 5th and extend to the following midnight. The forces concerned in producing these impulses are so strong that the direction in space from which they came must be regarded as well determined. The total magnetic force of the earth's field at Washington being taken as 0.61400 C. G. S. units, the maximum deflecting force imposed upon it was about 0.00250 C. G. S., or one two hundred and forty-sixth ($\frac{1}{246}$) of the permanent field. The resulting deflecting forces when transferred to a globe placed in the approximate astronomical position occupied by the earth for January 5, show clearly the presence of two magnetic fields, one directed towards the sun, undergoing the usual magnetic refraction belonging to the diurnal variations, as already indicated; the other, and this the true disturbance field, perpendicular to the plane of the ecliptic. At certain points the inter-play between these two fields is shown, but the marked character of the direction of the forces cannot be disregarded. The field perpendicular to the ecliptic occurs from 12 noon to 3.20 p. m., from 5 p. m. to 6.40 p. m., and from 8 p. m. to 10 p. m. On the sunny side of the earth the direction is from south to north, on the dark side from north to south, indicating an oscillation in opposite directions along the same line. The diurnal field occurs from 3.40 p. m. to 5 p. m. and from 7 to 7.30 p. m., according to the regular system. From 10.30 p. m. there sets in another field on the dark side of the earth.

It seems then that the existence of the two fields, one parallel, and the other perpendicular, to the ecliptic, the former continuously acting and the other spasmodic in its operation, can hardly be doubted. The treatment of the problem thus developed has the merit of wholly eliminating the action of the permanent magnetism of the earth from the data, leaving us free to discuss the disturbances and variations as an independent topic.

Disturbance of January 5, 1892.

Time.	ΔH	ΔD	ΔV	*dx*	*dy*	*dz*	σ	s	α °	β °	Remarks.
12......	+ 5.9	— 0.9	— 1.8	+ 266	— 58	— 148	272	310	—28	348	Perpendicular to the plane of the ecliptic.
12.30...	+ 6.2	— 1.0	— 2.0	+ 279	— 66	— 164	287	331	—29	351	
1.......	+ 5.8	— 3.9	— 2.0	+ 201	— 255	— 164	365	400	—25	315	
1.30....	+12.7	— 2.2	— 2.2	+ 572	— 144	— 180	590	617	—17	346	
2.......	+10.7	— 2.7	— 2.9	+ 482	— 176	— 238	513	544	—20	340	
2.30....	+12.4	— 0.4	— 2.5	+ 553	— 26	— 205	554	603	—20	358	
3.......	+ 9.2	— 0.8	— 3.0	+ 414	— 52	— 246	417	484	—31	353	
3.20....	+13.8	+ 0.8	— 2.8	+ 621	+ 52	— 230	623	664	—21	4	
3.40....	0.0	+ 3.8	— 2.0	0	+ 248	— 164	248	297	—34	90	Parallel.
4.......	— 6.8	+ 4.9	— 1.7	— 306	+ 320	— 139	443	464	—17	134	
4.30....	— 1.6	+ 0.8	— 1.6	— 72	+ 52	— 131	89	158	—56	144	
4.40....	0.0	+ 0.6	— 1.6	0	+ 40	— 131	40	137	—73	90	
5.......	+ 4.1	+ 0.6	— 1.4	+ 185	+ 40	— 115	189	221	—32	12	Perpendicular.
5.30....	+ 4.6	+ 1.3	— 1.4	+ 207	+ 85	— 115	224	252	—29	23	
6.......	+ 6.4	+ 2.0	— 1.9	+ 288	+ 131	— 156	316	352	—26	24	
6.20....	+11.1	+ 1.0	— 1.5	+ 500	+ 66	— 123	504	519	—14	6	
6.40....	+ 6.0	+ 5.0	— 1.2	+ 270	+ 327	— 98	424	435	—13	50	
7.......	+ 0.3	— 4.0	+ 4.7	+ 14	— 262	+ 385	262	466	+56	273	Parallel.
7.20....	+ 8.4	+ 9.6	+ 3.7	+ 378	+ 627	+ 303	732	792	+23	59	
7.25....	0.0	+ 7.0	+ 4.0	0	+ 458	+ 328	458	563	+35	90	
8.......	—15.0	—12.0	+11.2	— 675	— 784	+ 918	1035	1383	+42	229	Perpendicular.
8.30....	—14.0	—18.6	+13.0	— 630	—1215	+1066	1369	1735	+38	243	
9.......	— 6.7	— 2.0	+16.2	— 302	— 131	+1328	329	1369	+76	204	
9.20....	—30.0	—19.0	+19.7	—1350	—1241	+1615	1834	2444	+43	222	
10......	—11.0	—27.2	+10.6	— 495	—1777	+ 869	1845	2039	+26	255	
10.20...	—14.0	+11.0	— 8.0	— 630	+ 719	— 656	956	1159	—34	132	Parallel.
10.40...	— 5.6	+ 4.0	— 7.0	— 252	+ 261	— 574	363	679	—58	134	
11......	— 9.4	— 4.0	— 2.3	— 423	— 261	— 189	497	532	—22	212	
11.30...	— 8.0	— 5.2	— 1.2	— 360	— 340	— 98	495	505	—12	222	
12......	— 7.7	— 2.0	— 0.5	— 347	— 131	— 41	371	373	— 6	196	

ΔH, ΔD, and ΔV are millimeters measured from the dots which represent the normal diurnal curve.

dx, *dy*, *dz* are derived by the following constants:

H, 1 millimeter = .000045 C. G. S. units;

V, 1 millimeter = .000082 C. G. S. units;

D, 10′ = 8.86 millimeters.

σ, s, α, β are computed by the formulæ,

α, the altitude of the deflecting force from the horizon,

β, the azimuth of the same from the magnetic meridian in the direction n., w., s., e.,

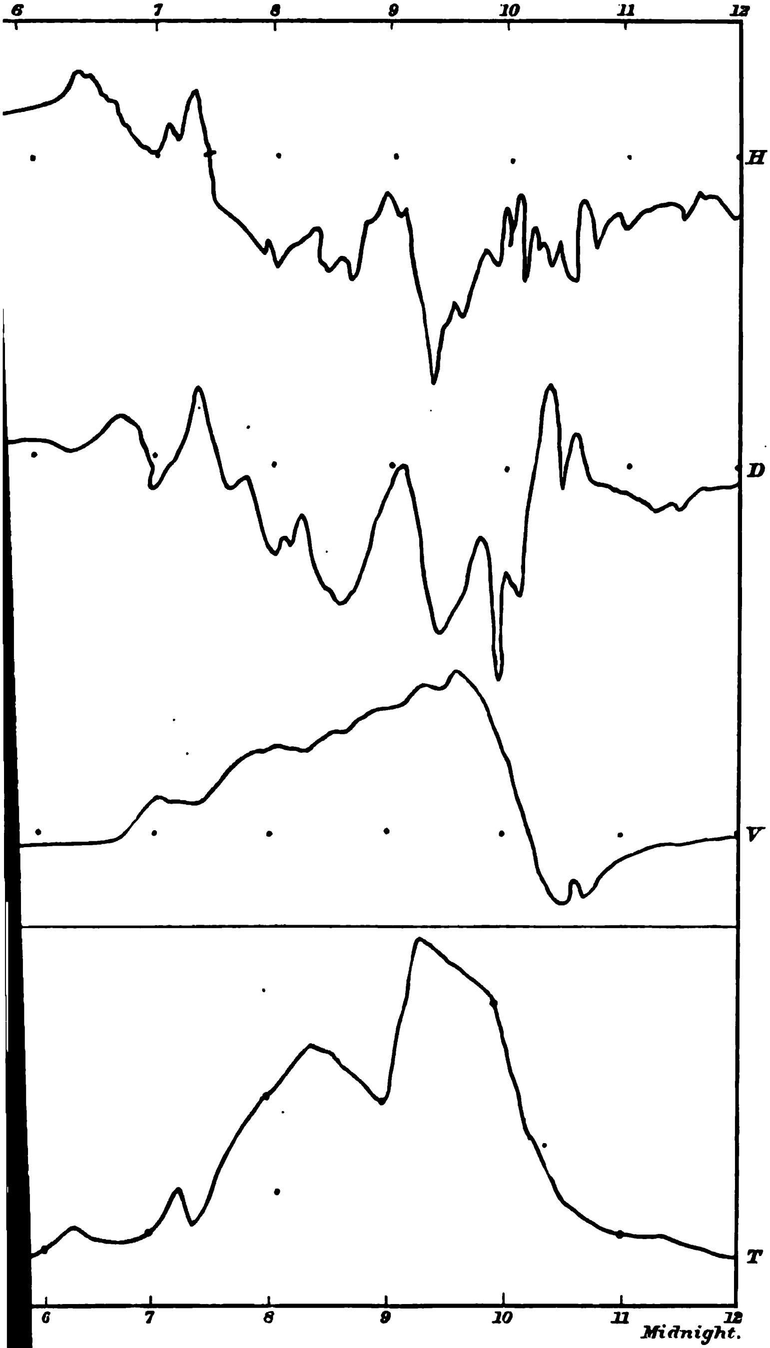
s, the deflecting force, in units of the fifth decimal place.

The globe is viewed from a point in the ecliptic opposite the six-hour circle, counted from noon, and is seen to represent its approximate position for January 5.

There is another method of accounting for the deflecting forces which act during the disturbances, so far as concerns their directions. The radiant field on entering the earth through its peculiar curvature divides itself into two portions, one characteristic of the polar regions, and defined by the action of a magnet nearly at right angles to the direction of the field; the other characteristic of the lower latitudes, and specified as simply a case of magnetic refraction. Now, when the solar energy intensifies, the radiant field in transmitting this energy strengthens and spreads the true polar field downwards over the normal low latitude field temporarily, so that during disturbances we have an alternate action of these two fields.

Thus, in the illustration, the first eight pins on the left belong to the polar field on the light side of the earth, and act upwards; the next four pins are where the disturbance force is lessened and the normal emergent field by refraction resumes its supremacy; then we have four more pins where the polar field is again intensified; next there are three pins where the entering forces of the radiant field appear, and are really continuous with the four forces of the radiant field just described; then come five pins with heads on, standing for the forces of the polar field on the dark side of the earth, which, in this case, must act downwards; finally, the four sharp pins represent the increased activity of the normal terrestrial field, which, at this latitude, has a dip of about 71°, and which may express the energy impressed upon the total permanent system of the earth by the antecedent stages of the induction. The peculiar distribution is such as to be referred with equal probability to either the coronal or the radiant fields, but it will be necessary to undertake a more extensive discussion of the systems of disturbances before this can be finally settled.

WASHINGTON, D. C., *April* 22, 1892.



5, 1892, Washington, D. C.

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U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 3.

A REPORT

ON THE

RELATIONS OF SOIL TO CLIMATE.

BY

E. W. HILGARD,
PROFESSOR OF AGRICULTURE AND AGRICULTURAL
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Published by authority of the Secretary of Agriculture.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., July 15, 1892.

Sir: I have the honor to transmit herewith a report on the Relations of Soil to Climate, by Prof. E. W. Hilgard, of the University of California, and to recommend its publication as Weather Bureau Bulletin No. 3.

Very respectfully,

Mark W. Harrington,
Chief of Weather Bureau.

Hon. J. M. Rusk,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

UNIVERSITY OF CALIFORNIA,
COLLEGE OF AGRICULTURE,
Berkeley, Cal., May 31, 1892.

SIR: I have the honor to submit herewith for publication a report on the Relations of Soil to Climate.

Very respectfully,

E. W. HILGARD.

MARK W. HARRINGTON,
Chief of Weather Bureau.

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THE RELATIONS OF SOIL TO CLIMATE.

Since soils are the residual product of the action of meteorological agencies upon rocks, it is obvious that there must exist a more or less intimate relation between the soils of a region and the climatic conditions that prevail, or have prevailed therein. It is the object of this paper to discuss, both from the theoretical and practical standpoint, some of the more important phenomena dependent upon this correlation, and their effects upon the agricultural peculiarities of the chief climatic subdivisions.

In order to render this discussion intelligible to the general reader it will be best to summarize, as briefly as may be, the several agencies that contribute toward the process of soil formation from rocks and their decomposition products.

THE PROCESSES OF SOIL FORMATION.

HOW SOILS ARE FORMED.

a. **MECHANICAL AGENCIES.**—The chief *mechanical* agencies concerned are the following, mentioned in the order in which they usually follow one another in nature :

1. Effects of *changes of temperature*, whereby the several minerals of which many rocks are composed are differently affected, so that their close adhesion is gradually weakened, and minute cracks are formed which give access to water and air, and to the small rootlets of plants.

2. Effects of *freezing water*, which widen still farther the minute crevices by its irresistible expansion, and in the case of the larger cracks rend rock masses into fragments, thus increasing the surfaces exposed and facilitating the removal of the rock from its original site, whether by gravity, moving water, or wind.

3. Effects of *moving or flowing ice* (glaciers). While at present confined to relatively limited areas, yet the powerful action of glaciers in grinding rocks to fine powder, from which soils form with great rapidity, renders this agency of great importance even at the present time; while in the past the enormous areas known to have been glaciated are covered largely with soils produced by this process conjointly with that of the water resulting from the melting of the ice. The rocks carried on the surface of glaciers are subject in the highest degree to the effects of changes of temperature, becoming intensely heated during clear days by the sun's rays when unaffected by the denser portions of the atmosphere, and at night again subjected to frost. These fre-

quent and violent changes assist greatly the merely mechanical grinding and abrading process resulting from the ice movement, both on the surface, within the ice mass (in the "crevasses"), and on the lower surface, which in the course of time becomes lined with stones that score the rocky bed with deep furrows. Hence glacier streams are always notable for the large proportion of very fine rock powder carried by them.

4. The effects of *flowing water* are doubtless at this time the most potent agencies of soil formation. Apart from the mere removal of loose materials from one point to another, its effects in carrying sand, gravel, and bowlders, according to velocity and volume, are prodigious. For these rock fragments not only score the bed of the stream or rill, but by their mutual attrition and abrasion produce more or less of fine powder similar to that produced by glacial action, but usually much more mixed in its ingredients, because derived from a wider range of surface. "Alluvial" soils thus formed are usually the most generalized in composition, while the "colluvial" soils of rolling uplands and slopes generally, are commonly, like those derived from glaciers, more of a localized character.

b. CHEMICAL AGENCIES.—The *chemical* processes that contribute essentially to the formation of soils are these:

1. *Solution by water alone.*—Since few substances known, and especially few of those forming rocks, are entirely insoluble even in pure water, while some (like gypsum) are easily dissolved in the latter, even rain-water carries these effects with it wherever it falls. But practically no pure water is found in nature, and it has required the utmost refinements of apparatus and manipulation to obtain it even artificially. The impurity which it almost invariably carries is an apparently weak, but in its ultimate effects very powerful, agent, viz.:

2. *Carbonic acid.*—The acid of "soda water," produced naturally by all processes of decay, fermentation, and slow or rapid combustion of vegetable and animal substances, coal, etc., as well as by the breathing of animals. Being contained in the air, this acid gas is absorbed in rain water and imparts to it additional solvent properties; being continually generated in the soil by the decay of the vegetable matter, it renders the soil water a relatively strong, acid solvent, which acts steadily upon the mineral matters of the soil and decomposes them still further, rendering their ingredients available for the nutrition of plants.

3. The *oxygen of the atmosphere* is active not only as taking part in the formation of carbonic acid, but also directly, in its action upon certain ingredients of rock minerals, notably the iron compounds. Most green and black minerals contain iron in a form (protoxide) which is capable of taking up more oxygen when opportunity is afforded. This occurs when carbonic acid water acts on the minerals containing the iron; the latter is then often completely eliminated in the form of

"rust" (ferric hydrate), causing the minerals and rocks to change their color from green or black to yellow or reddish, and by the increase of bulk softening or pulverizing the rock; while at the same time the carbonic acid dissolves and carries off, in water solution, a large proportion of the other ingredients.

4. In some cases, *water* enters directly into combination with the substances present or newly formed; thus increasing the bulk of the mass and forcibly rending the original structure. This happens in the formation of clay from feldspars, of gypsum from the mineral anhydrite, in the changing of black "ferrous" minerals into rusty brown, and in numerous other cases.

WEATHERING AND FALLOWING.—Thus the combined chemical action of water, carbonic acid, and oxygen, facilitated by the mechanical pulverization of the rocks, is most potent and constantly active in disintegrating both rocks and soils. Aside from the purely mechanical action of flowing water and ice, the effects of all the above agencies are comprehended under the term "weathering," and in agricultural practice, "fallowing."

CLASSIFICATION OF SOILS.

According to the predominance of the several agencies enumerated, the soils resulting from their action may be classified into three chief divisions, viz.:

1. **SEDENTARY OR RESIDUAL SOILS**, or soils in place, which result from the quiet action of changes of temperature, frost, etc., in pulverizing the parent rock, together with the solvent action of water charged with carbonic acid and oxygen, but without any removal from the site of the original rock.

2. **TRANSPORTED SOILS**, which have been more or less removed from their original source, prevalently by the action of water, but also by the aid of gravity and winds. They naturally subdivide into two primarily important and universally recognized subdivisions, viz.:

a. Colluvial soils, consisting of materials that have been transported short distances only and have not undergone any sedimentation or stratification in flowing water of watercourses, and the distribution of which bears no obvious relation to the latter. They may therefore contain débris of all sizes more or less uniformly distributed through their mass; and they form the bulk of upland and slope soils. In the regions covered by glacial drift, their materials may have come from great distances; but still the soil mass is destitute of any definite structure, such as belongs to—

b. Alluvial or sediment soils, which have been deposited in and from flowing water, therefore occupy areas distinctly related to present or former watercourses or lakes, and have a more or less distinct stratified or bedded structure, according to the nature of the depositing current or basin. The alluvial class therefore includes all "bottom" and "second bottom" valley soils, as well as those of ancient or modern lakes and swamps.

It is hardly necessary to say that between these several classes of soils there is every degree of transition, and that it is frequently a matter of choice whether a given soil shall be considered as belonging to one or the other class. This is especially true of the older alluvial soils, many of which in the course of time have virtually become upland soils by the subsidence of the water or the rising of the land and its consequent erosion into hills. The great plains of the West, and many of the "mesa" lands of the continental interior and Pacific coast of America, are instances in point, and so are the ancient river terraces now lying high above the present flood-plains.

PHYSICAL NATURE OF SOILS.

Speaking in the most general terms, all soils may be considered as consisting of more or less finely powdered and decomposed *rock* (sand, silt), *clay*, and *vegetable matter* changed to greater or less extent toward the condition of humus or vegetable mold. The relative proportions of these three principal physical constituents determine the most general classification of soils according to their nature; as *sandy* or *light*, *clayey* or *heavy*, and *humus*. Beyond these, the degree of fineness of the rock débris and their chemical and physical constitution determines distinctions such as gravelly, sandy, silty, loamy, calcareous, siliceous, magnesian, ferruginous, and others of less general application although locally often of considerable importance.

CLIMATIC FACTORS THAT MODIFY SOILS.

INFLUENCE OF TEMPERATURE ON SOIL FORMATION.

Within the ordinary limits of atmospheric temperatures, all the chemical processes active in soil formation are intensified by high and retarded by low temperatures, all other conditions being equal. We can artificially imitate and produce in a short time, by the application of high temperatures, most of the chemical changes that naturally occur in soil formation.

This being true we should expect that the soils of tropical regions should, broadly speaking, be more highly decomposed that those of the temperate and frigid zones. While this fact has not been actually verified by the direct comparative chemical examination of corresponding soils from the several regions, owing to the want of uniformity in methods and the fewness of such investigations in tropical countries, yet the incomparable luxuriance of the natural as well as artificial vegetation in the tropics, and the long duration of productiveness*

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*A special case in point is that of the fertile tract of volcanic soils extending between the cities of Guatemala and Antigua, that have been cultivated from the earliest times of settlement. When fresh these lands yielded about 75 bushels of maize. They have now fallen off to 15 to 20 bushels, but it has taken centuries to bring about this change.

that favors so greatly the proverbial easy-going ways and slothfulness of the population of tropical countries, offers at least presumptive evidence of the practical correctness of this induction. In other words, the fallowing action, which in temperate regions takes place with comparative slowness, necessitating the early use of fertilizers on an extensive scale, has been much more rapid and effective in the hot climates of the equatorial belt, thus rendering available so large a proportion of the soil's intrinsic stores of plant food that the need of articial fertilization is there restricted to those soils of which the parent rocks were exceptionally deficient in the mineral ingredients of special importance to plants, that ordinarily form the essential material of fertilizers. Quartzose, magnesian, and other soils resulting from the decomposition of "simple" rocks will everywhere be poor in plant food; again, the intense decomposing or fallowing effect of tropical climates may be offset by an equally intense leaching process in consequence of copious rainfall. An example of this apparently occurs in the Hawaiian Islands, in the highly ferruginous soils resulting from the decomposition of the black (hornblendic) lavas that are so characteristic of the volcanic effusions of that region. The soils formed from these are sometimes so rich in ferric hydrate (iron rust) that they might well serve as iron ores elsewhere; often having from 30 to 40 per cent. of that substance. But as these soils are very unretentive, though very productive at first, they are soon exhausted; the abundant rains having apparently deprived them of almost every vestige of lime, and of most of the potash contained in the original rock. To return lime to them would seem to be the first thing needful in restoring their producing powers, and the coral sand of the beaches would offer a cheap source of supply of that substance. A more detailed discussion of some of these points is given further on.

INFLUENCE OF RAINFALL ON SOIL-FORMATION.

Since water is the prominent agent in the process of soil formation, it follows that the variations in its supply, in other words, the greater or less amount of rainfall, must affect materially that process. In addition, and especially in connection with the rainfall, the *temperature* conditions, already referred to, and the *manner of distribution of rains through the seasons* in connection therewith, are potent factors.

Leaching of the land.

One of the most obvious results of an abundant rainfall is the leaching-out of the more soluble portion of the rock constituents that have been formed or set free by the process of weathering.

The extent to which this leaching occurs depends of course largely upon the perviousness of the soil material to water; it is greatest in "leachy" soils, *i. e.*, those in which not only the surface layer but also the substrata are so coarsely sandy as to permit a very rapid passage of water in all directions. From this extreme, through sandy and clayey loams to heavy clay soils, there is every gradation of perviousness to almost impermeability. Whatever water falls on the latter class of soils will largely run off from the surface, hence cannot leach out of them what, in the case of "lighter" soils, is carried currently into the country drainage.

Composition of sea water.

The usual nature of the substances so leached out is well illustrated in the salts of sea-water, which represent the generalized result of countless ages of this leaching process.

Mean composition of sea water (according to Regnault).

Sodium chloride (common salt)	2.700
Potassium chloride	.070
Calcium sulphate (gypsum)	·140
Magnesium sulphate (Epsom salt)	.230
Magnesium chloride (bittern)	.360
Magnesium bromide	.002
Calcium carbonate (limestone)	.003
Water (and loss in analysis)	96.495
	100.000

The average saline contents of sea water would thus be 3.505 per cent. In twenty-one determinations of the saline contents of the Atlantic Ocean, the percentage ranged from 3.506 to 3.710 per cent. Of this mineral residue, common salt constitutes from about 75 to over 80 per cent.

We see that most prominent among the ingredients mentioned here is common salt (sodium chloride), which forms nearly four-fifths of the total solid contents. Next in quantity are the compounds of magnesium, viz., Epsom salt and bittern, with a very small amount of the bromine compound. Next come the compounds of calcium (lime), of which gypsum is the more abundant, while the carbonate, so abundant on the land surface in the various forms of limestone, is present in minute amounts only, yet enough to supply the substance needed for the shells of shellfish, corals, etc. Least in amount of the metallic elements mentioned is potassium, which, like sodium, exists mainly in combination with chlorine. Calculating the total amounts of the latter substance, we find that it exceeds in weight any one other element present in the salts of sea water, being two-sevenths of the whole amount.

Substantially the same result, with variations due to local causes, is obtained when we consider the saline ingredients of lakes having no outlet, and in which therefore the leachings of the tributary land area have accumulated for ages. The Great Salt Lake of Utah, the landlocked lakes of the Nevada basin, of California, Oregon, and of the deserts of Asia, Africa, and Australia, all tell the same tale, which may be summarized in the statement that the chlorides of sodium and magnesium and the sulphates of sodium, magnesium, and calcium constitute the bulk of the leachings of the land, while of other substances potassium alone is present in relatively considerable amount.

While the above analysis shows the ingredients of sea water so far as they can at present be directly determined by chemical analysis, yet the presence of many others is demonstrable, directly or indirectly, from various sources. One is, the mother waters from the making of sea salt, in which such substances accumulate so as to become ascertainable by chemical means, and even become industrially available in the cases of potash and bromine. Another is the ash of seaweeds, which is indisputably derived from the sea water, and contains, among other substances not directly demonstrable in the original water, notable quantities of iodine (of which this ash is the commercial source), iron, manganese, and phosphoric acid. Again, the copper sheathing of vessels, as it is generally corroded, becomes more or less rich in silver, manifestly thrown down from the sea water, and the silver so obtained is associated with minute amounts of gold. Copper, lithium, and fluorine likewise have been found in sea water; and it is probable that close search would detect very many of the other chemical elements as ordinary ingredients in minute amounts. This is what must be expected from the fact that few mineral substances known to us are entirely insoluble in pure water, and still fewer in water charged with carbonic acid. The latter is always present in sea water and holds the lime carbonate in solution; on evaporation or boiling, this substance is the first to be precipitated; and thin sheets of limestone from this source are commonly found at the base of rock-salt beds, which, themselves, are evidently the result of the evaporation of segregated bodies of sea water in past geological ages.

Summing up the facts concerning the water of the sea and of landlocked lakes, with reference to the ingredients of soils needful for the nutrition of plants, it appears that the rock ingredients leached out in the largest amounts are those of which the smallest quantities only are required by most plants; while of those specially needful for plant nutrition, only potash is removed in practically appreciable amounts by the country drainage.

Insufficient rainfall.

When, however, the rainfall is either in total quantity, or in its distribution, insufficient to effect this leaching, the substances that otherwise would have passed into the sea are wholly or partially retained in the soil stratum and when in sufficient amount may become apparent on the surface in the form of efflorescences of "alkali" salts. The presence of the latter is therefore almost always an indication of scanty rainfall, and of other important peculiarities which will be considered more fully hereafter.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE PHYSICAL CHARACTER OF SOILS.

While it is not possible to separate strictly the physical or mechanical from the always more or less concurrent chemical differences caused by climatic influences, some general considerations on the former should precede the discussion of the latter class.

EFFECTS OF ARID AND HUMID CLIMATES ON THE FORMATION OF CLAY.

One of the most important modifications produced by scantiness of rainfall on soil formation is the great retardation of the formation of clay from feldspathic rocks (kaolinization) and the sediments derived therefrom. An often-quoted example of this influence is that of the quarries of Syene in Upper Egypt, where most of the great monoliths employed in the construction of the monuments and temples of Egypt were obtained. In this quarry, which has not been worked for at least two thousand years, the rough blocks that were in progress of quarrying when the work was finally abandoned are said to show an almost perfectly fresh surface to this day; and a well-preserved surface is also shown by the obelisks and pillars made of the same material and transported to lower Egypt, where, however, the rainfall is somewhat greater. It is a matter of public note that one of these monuments (Cleopatra's Needle) for some time set up in the Central Park at New York, is in great danger of destruction from the influence of a totally different climate, in which not only the rainfall but the temperature changes are very much greater than in Egypt. Both factors combined will, of course, prove even more destructive than one alone would be, for a change of temperature that has resulted in the opening of fine cracks at the joints of the mineral components, if followed by a rain and a subsequent freeze, may produce a greater effect in a few days than a thousand years of Egyptian climate would have accomplished. In the case of the obelisk at New York, the physical effects just mentioned are doubtless the chief factors of destruction; while the chemical process of kaolinization is too slow to be noticeable at once, although it is clear that it will be enormously accelerated by the breaking-up of the rock caused by the purely physical agencies.

A similar contrast is found in comparing the granitic rocks of the southern Alleghanies with the corresponding rocks in the arid plateau region west of the Rocky Mountains, as well as in California and Arizona. The sharpness of the ridges of the Sierra Madre, and the roughness of the hard granitic surfaces, contrasts strikingly with the rounded ranges formed by the "rotten" granites of the Atlantic slope, where sound, unaltered rock can sometimes not be found at a less depth than forty feet. What is true of granite holds correspondingly, of course, in the case of other rocks.

The inference is that a corresponding difference should manifest itself in the soils formed under the influence of these diverse climatic conditions; and even the most cursory observation shows this to be the case. The result may be expressed in the general statement, that while the soils of the Atlantic slope are prevalently loams, containing considerable clay, and even in the case of alluvial lands oftentimes very clayey or heavy, the character of the soils of arid regions is predominately sandy or silty, with but a small proportion of clay, unless derived, directly or indirectly, from pre-existing formations of clay or clay shales. Of course the character of these "sedentary" clay soils is substantially independent of climate, their substance having been formed in past geological ages.

LIGHT SOILS PREDOMINATE IN ARID CLIMATES.

This incoherence of the soil material in arid climates, resulting from the scarcity of clay,* becomes obvious to the traveler in the sand and dust storms that sometimes annoy him while traversing, *e. g.*, what has been conventionally known as the "Great American Desert," a desert only so long as the life-giving influence of water is withheld from it. Droughts may render the surface of the country in the Atlantic States, or in Europe, as dry as the great plains themselves; yet away from highways or cultivated fields little or no dust will ordinarily be raised by the strongest wind, because of the coherence of the soil, which will generally be found covered by a hard-baked crust. In the arid region, under the same conditions, a mere puff of wind may raise a cloud of dust, and a wind storm becomes almost unavoidably a sand or dust storm also. "Dust soils," which during the dry season are even in their natural condition so loose as to rise in clouds and render travel very uncomfortable, are not uncommon in Washington and adjacent parts of Oregon, on the uplands bordering the Columbia and Snake rivers. The mechanical and chemical analyses of three such soils, given in the table below, will convey some idea of their peculiarities in both respects.

The same general facts are known of the other arid regions of the globe, whether in Asia, Africa, or Australia.

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*It must be distinctly understood that what is meant here by "clay" is not the mineral kaolinite, but the gelatinous, plastic "colloidal" substance that results from its physical disintegration, and alone plays the part of rendering the soils coherent.

Dust soils of arid region.

CHEMICAL ANALYSIS OF FINE EARTH.

	17	37	79
	Atahnam Prairie, Yakima Co., Wash.	Rattlesnake Creek, Kittitas Co., Wash.	Plateau on Willow Cr., Morrow Co., Oreg.
Insoluble matter	71·67 } 76·78	78·33 } 80·53	79·21 } 81·51
Soluble silica	5·11	2·20	2·30
Potash (K_2O)	1·07	·70	·89
Soda (Na_2O)	·35	·24	·05
Lime (CaO)	2.00	2.08	1·37
Magnesia (MgO)	1·34	1·47	1·08
Br. ox. of manganese (Mn_3O_4)	·04	·07	·06
Peroxide of iron (Fe_2O_3)	6.88	6.13	5·63
Alumina (Al_2O_3)	7·91	6.12	6.02
Phosphoric acid (P_2O_5)	·13	.18	.18
Sulphuric acid (SO_3)	·02	·02	·03
Water and organic matter	2.82	2·35	2·55
Total	99·33	99·90	99·35
Humus	4·10	....	·44
Hygroscopic moisture	4·98	3·20	4·92

MECHANICAL ANALYSIS OF FINE EARTH.

	17	37	79
Clay	·93	3·59	1·27
Sediment of <.25 millimeters hydr. val	30·93	13·06	32·29
Sediment of .25 to .5 millimeters	3·20	5·82	12·75
Sediment of .5 to 2.0 millimeters	7·18	27·37	37·51
Sediment of 2.0 to 8.0 millimeters	21·88	43·78	10·92
Sediment of 8.0 to 64.0 millimeters	32·39	4·57	3·97
Total	96·57	98·18	98·72

Several points of interest that will be discussed in detail further on are illustrated in this table. In their chemical composition the three soils are very good illustrations of generalized soils of the arid region; they also show that the "clay" of physical analysis is not even approximately represented by the "alumina" of the chemical analysis; and that, moreover, the latter substance is not contained in these soils in the form of clay only, since the amount of "soluble silica" is far below that of alumina, while the reverse should be true if they were originally combined to form clay.

As regards the physical composition, "clay" is shown to be present in very small amounts only; there is a good deal of the finest silt, $<.25^{mm.}$; and then there occurs a conspicuous break in the small amounts of sediments just above that point. It may be casually mentioned here that soils of this character are irrigated with difficulty, the water penetrating so slowly that ditches must be run a few feet apart and the flow continued for a considerable length of time in order to soak the land.

It will also be noted that the percentages of the mineral plant food in these soils are quite large, and that according to all experience they should be found profusely and permanently productive. This forecast is abundantly confirmed by local experience.

STRONG SOILS.

But so generally has the idea of inherent fertility been associated, in the humid regions, with soils of more or less clayey character, that the terms "strong," "substantial," "durable" are habitually applied to them in contradistinction from "light," "unsubstantial" ones of the sandy or silty type. Hence the newcomer will frequently be suspicious of the productiveness and durability of soils in the arid region that experience has proved to be of the highest type in both respects.

The clayey soils that *do* occur in the arid regions (in California and Spanish America, generally known as "adobe"*) owe their existence to one or both of two precedent conditions. Those occupying upland slopes are mostly — though not invariably — directly derived from the disintegration of clay shales that either underlie or occupy a higher position on the slope; they are therefore either sedentary (soils in place) or colluvial, and derive their clay from that which was formed in former geological ages. The valley adobe lands, on the contrary, are mostly paludal or swamp formations (therefore not formed under "arid" conditions), and represent either the finest materials that remain suspended in slack water, from any source, or sometimes the direct washings of the clayey hill soils, above mentioned. Examples of both kinds are abundant in the Great Valley of California as well as in the Coast ranges of that state.

GREAT DEPTH OF SOIL IN ARID CLIMATES.

But it is not only in this point that the physical composition of the soils of arid climates differ from those of humid regions. Another point of great importance is that the difference between soil and subsoil, which is so striking and important in regions of abundant rainfall, is largely obliterated in arid climates. Very commonly hardly a perceptible change of tint or texture is found for depths of several feet; and what is more important, material from such depths, when thrown on the surface, oftentimes subserves the agricultural uses of a soil nearly or quite as well as the original surface soil. The unconcern with which irrigators proceed to level or otherwise grade their land, even though this may involve covering up large areas of surface soil with subsoil from several feet depth; the rapidity with which the red loam of the placer mines of the Sierra Nevada foothills is recovered with the natural forest growth of the region, are examples familiar to the residents but surprising to newcomers, who are accustomed to dread the upturning of the subsoil as likely to deprive them of remunerative crops for several years, until the "raw" subsoil has had

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* It is to be regretted that in the publications of the U. S. Geological Survey this name has been erroneously applied to the loam commonly used in the construction of adobe houses. Agriculturally it means "a heavy clay soil," such as could not be used in building.

time to be "vitalized" by the fallowing effect of the atmosphere, and to acquire the needful amount of humus, or vegetable mold.*

The cause of this difference is readily understood when we consider what it is that causes the contrast between soil and subsoil in humid climates. As before stated, soils are there, as a rule, richer in clay; this clay, becoming partially diffused in the rain water when a somewhat heavy fall occurs, percolates the soil in that condition and tends to accumulate in the subsoil; the result being that, almost without exception, the subsoils of the humid regions are very decidedly more clayey than the corresponding surface soils. It is only in alluvial lands formed by periodic overflows, which bring down deposits of varying nature at different times, that any material departure from this rule is found; more rarely it occurs in the case of colluvial soil overlying sandy beds, but supplied with clayey matter from a higher-lying outcrop.

But not only does this clay water tend to render the subsoil more compact and heavy, making it less pervious to water and air, but it is assisted materially in this by the action, discussed below, which tends to leach the lime carbonate out of the surface soil into the subsoil. The accumulated clay is thus frequently more or less cemented into a "hardpan" by lime, partly in the form of carbonate, partly in that of zeolitic (hydrous silicate) compounds; adding to the compactness of the subsoil, and therefore to the usual specific difference between soil and subsoil, viz., the deficiency or absence of humus, and the difficulty of penetration by and aëration of the roots of plants. This point will be further considered below.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE FORMATION OF HUMUS.

Succeeding more or less closely, in time, the physical and chemical agencies upon which depend the formation of soils from rocks and the continued decomposition of the rock powder in soils themselves, there comes another which is most intimately connected with plant growth, and scarcely second in importance to those already referred to. This is the decay of vegetable matter in the soil and the formation of what, in a comprehensive way, is known as humus or vegetable mold—the dark-colored, sometimes jet-black remnant of vegetable decomposition under at least partial exclusion of air. While now known not to possess that exclusive importance for vegetable nutrition that was at one time attributed to it, humus is still recognized as one of the most important soil ingredients for the purposes of practical agriculture; and

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*In the case of a cellar 7 to 10 feet deep, near Nevada City, Cal., the red subsoil mass dug out was spread over a part of a vegetable garden close by, and as a venture the annual vegetables--tomatoes, beans, watermelons, etc.—were sown just as usual. They not only did well, but even better than the portions not covered, which had been cultivated for a number of years and were somewhat exhausted thereby. Even material from 30 feet depth has acted similarly.

as its formation is directly dependent upon climatic conditions, its variations in accordance with them form essential points of difference between the soils of humid and arid regions.

Vegetable matter exposed to the action of the air alone will, in the course of time, be completely destroyed by the slow process of combustion (eremacausis), which is unaccompanied by any essential fermentative action and is materially assisted by an elevated temperature. When submerged in water it undergoes a very different process, namely, a gradual conversion into a brown mass, of which the extreme result is peat. The coffee-colored waters of peat bogs prove that this substance, or a portion of it, is soluble in water; and these brown waters are distinctly acid to test papers and sometimes even to the taste. Hence the popular designation of soils formed or existing under such conditions as "sour," is strictly correct; and it is well known that the correction of such lands by means of drainage, and the neutralization of the acidity in the soil (usually, in practice, by marling), are conditions-precedent of their profitable cultivation.

Peat bogs, properly so called, can exist only in cold-temperate, humid climates; not only because the peat moss, which forms their chief vegetation, can not flourish in dry air, but also because the vegetable matter accumulating under water in warm regions undergoes a more rapid fermentation, whereby much of it is converted into gaseous products (carbonic and marsh gas), and the peaty or humus residue is greatly less in amount. But the conditions for the formation of "sour" soils may be realized in *any* climate, in the presence of water, as in the "tule" or marsh lands of California, as well as of Louisiana and Florida, or in the heads of ravines where springs or oozes of water constantly flow. But in the marshy Arctic lowlands or tundras the low temperature maintained even during the short summer renders the progress of humification extremely slow, preventing the formation of true peat even where the peat moss can maintain its existence.

When, on the contrary, vegetable matter decays *underground* in well-drained land, the process of humification has a result different from either of the two preceding cases. The humus formed is of a darker and sometimes jet-black tint, and it imparts no color to water percolating through the soil, being completely insoluble. It is this kind of humus that is desired by the farmer everywhere; it is hailed by him as the mark of high productiveness in the case of new lands, and he considers the maintenance of a proper proportion of it in the cultivated land as essential to profitable culture.

It should be noted right here that the brown humus of bogs is not only neutralized in its acidity by lime, but it is also rendered insoluble in water by its action; and in the course of time is transformed into true, black, insoluble humus.

A product intermediate between peat proper and true soil humus is found forming the surface of the primeval forests of the coast region of northwestern America, from middle Oregon to Alaska. It is known to the inhabitants as "duff," probably from its resemblance to the holiday pudding of seafaring men, that is usually colored by molassas or brown sugar. The natural "duff" is the result of the decay, above ground, of the countless trunks of fallen trees that so commonly obstruct the passage of any but the most agile pedestrian in those regions, and upon which the new generation of trees frequently finds a most congenial starting point and foothold. In the course of time, in a climate in which daily rains are the rule rather than the exception, these trunks flatten out and in the aggregate form a surface covering occasionally several feet in thickness, on which rank mosses, *Linnæa*, various pyrolas, prince's pine, and similar plants flourish in dense masses, while grasses or anything else affording pasturage are conspicuously absent. The brown tint of the surface layers of the "duff" gradually deepens as the depth increases, and finally there is an insensible transition into normal, black soil.

INFLUENCE OF ARIDITY UPON THE FORMATION OF HUMUS.

It is easily seen that under the influence of hot, rainless summers, the process first mentioned above, viz., eremacausis or slow combustion, which leaves little residue beyond the mineral ash of the vegetable matter, must prevail very largely; and that, exceptional circumstances apart, the previous soils of the arid regions are likely to contain less humus than those of humid climates. Broadly speaking, actual examination amply proves this presumption to be correct, and among the agricultural practices which prove very successful in the eastern United States but largely fail west of the 100th meridian is one bearing on this very point. Straw or strawy manure cannot be profitably plowed in, in its raw condition, in the arid regions, because of its failure to decay and become a portion of the soil within any reasonable limit of time. Hence these precious materials were, during the earlier years of Californian agriculture, most commonly burnt to get them out of the way, so as not to interfere with the success of crops by keeping the soil too open, thus preventing the germination and rooting of the grain. The rapid burning of the straw really did little more than to accomplish in a short time what in the course of nature would have taken two or three years by the agency of slow eremacausis.

Ordinarily it was only through the winter months that any material amount of humification could take place under the influence of moisture and an only moderately low temperature.

Climatic conditions thus compel the farmer of the arid region to "cure" or compost his straw or manure before using them on the field, unless, indeed, he can so far control the climate by the command of irrigation water as to restore, substantially, the humid conditions necessary for the rapid fermentation of manure in the soil itself, and for the humification of dry straw or refuse. The extra labor thus involved is a material drawback to the free utilization of stable-yard manure, and of all dry vegetable refuse of the farm, and there thus arises a natural inclination toward the use of the easily applicable commercial fertilizers whenever fertilization becomes necessary. That the openness of most of the soils, and the high summer temperature, must in a measure modify the selection and the mode of application even of these is obvious. To be effective and utilized to the best advantage they must be put in to a greater depth than would be required where the surface soil is not liable to become air-dry, and perhaps quite hot, during the summer days; for otherwise the roots would be induced, in following the direction of greatest food supply, to come within dangerous proximity to the arid surface.

These considerations apply mainly, of course, to the characteristic soils of arid climates—the silty and sandy ones, which are the result of a general process, and not of the disintegration, in place of clayey beds or clay shales, or of slow deposition in river or littoral swamps. For in these the atmospheric influences are so far limited by their closeness, as well as by their tenacious retention of moisture, that the process of humification can proceed under much more favorable conditions; and hence we find among this class of soils (black adobe) very much larger humus percentages, approaching nearly to those of the soils of the Mississippi Valley.

Few of the characteristic upland soils of the arid region contain over .40 per cent. of true humus,* the fruit-growing "mesa" soils of south California mostly fall below one-fourth of one per cent. (.25 per cent.) In the humid region of the cotton states three-fourths of one per cent. is a common amount, and few even of the pine-woods soils fall below one-half per cent. This difference is important because the humus of the soil is the repository of that highly important soil ingredient, nitrogen, the replacement of which is the most costly of all where clovers cannot be used for green manuring.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE CHEMICAL PROCESSES IN AND CHEMICAL NATURE OF SOILS.

Owing to their intimate interdependence the chemical processes that are constantly active in soils have to some extent been mentioned already in connection with the discussion of the physical characters. They will now be considered more in detail in their connection with climatic conditions.

THE LEACHING PROCESS.

One material difference caused by a copious rainfall as compared

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*That is *matière noire* as determined according to Grandeau's process of extraction, the only method by which unhumified organic débris can with certainty be excluded from the determination. Both combustion and extraction with alkaline lye yield results of no value, varying widely with the season in one and the same soil.

with a scanty one, has been mentioned in the current leaching out of the easily soluble alkali salts, notably those of sodium, and to some extent of potassium also, together with certain easily soluble earthly compounds (sulphates and chlorides of calcium and magnesium), and occasionally of other locally abundant soluble substances. These salts, being carried through the soil into the country drainage, gradually accumulate in the basins finally receiving the same, whether oceans or inland lakes.

In arid regions these salts are, on the contrary, retained in the soil to a greater or less extent; they tend naturally to accumulate in the lower ground, toward which they are carried by the occasional rainfalls, as well as by the general seepage.

Before considering in detail the effects of this retention of the salts commonly known as soluble, it is necessary to discuss the effects of climate upon another substance, viz., lime carbonate, commonly presented to us in the form of limestone and chalk.

LIME CARBONATE IS SOLUBLE.

Although ordinarily considered insoluble in water when in the form of marble, limestone, or chalk, lime carbonate is yet sufficiently soluble in the soil water—always more or less charged with carbonic acid—to be materially affected by the leaching process. While much less soluble than the salts of potassium, sodium, or magnesium, and also less than gypsum or lime sulphate, yet the constant tendency is to leach it out of the surface soil into the subsoil, and from the soils of the uplands into those of the lowlands. We shall, therefore, expect to find, ordinarily, each subsoil a little richer in lime carbonate than its surface soil; and the valley soils more calcareous than those of the adjacent uplands. A comparison of a series of such analyses clearly demonstrates the overwhelming prevalence of this difference, so far as the contents of easily soluble lime are concerned; but owing to the fact that the surface soil is more fully exposed to atmospheric influences than the subsoil, the former may at times be found to contain more actual *carbonate* than the subsoil (where it often suffers transformation into other compounds). Such a time is at the end of the dry season, during which (as Storer has first shown) lime carbonate is formed from other compounds of lime; a highly important part of the "fallowing" process. But during the following rainy or winter season the carbonate is again washed into the subsoil, so that in humid climates it may in spring be almost absent from the surface soil itself.

But this being so, it follows that in arid climates, in which the rainfall is insufficient to leach the soil even of its very easily soluble alkali salts, the lime carbonate must of necessity accumulate to even a greater extent than the former. We should therefore expect to find the soils of the region west of the 100th meridian in the United States, and generally those of arid regions everywhere, richer in lime than those of the humid regions, and particularly of those having abundant and frequent rains during a warm summer. For under the latter conditions the fermentation and oxidation of vegetable matter in the soil is very active, generating a large amount of carbonic acid, which is taken up by the soil water and readily dissolves lime carbonate; and the rainfall being sufficiently copious, this solution is carried through porous soils and subsoils into the country drainage.

Striking exemplifications of this action are sometimes seen in the case of lands either naturally very calcareous, or made so by marling, and underdrained by tile. After a number of years, not only will the tile be found incrusted more or less with lime carbonate in the form of "sinter" or tufa, but sometimes, where the flow is habitually somewhat arrested, the accumulation may become so great as to seriously obstruct small tiles, which it therefore is inadvisable to use in such soils. The principle involved here is precisely the same as that upon which depends the formation of stalactites in limestone caves, as well as that of the latter themselves.

We shall thus expect to find the upland soils in the region of summer rains relatively poor in lime;. unless indeed they are underlaid more or less directly by, or derived from, some geological formation rich in that substance, from which the supply is kept up. Such is the case in the "residual" soils of the "prairies" of the Mississippi valley; and generally in limestone regions. And since, lime is an exceedingly important soil ingredient, conditioning very materially the thriftness of soils, it has in the humid regions become a common adage that "a limestone country is a rich country." This is true, at least, wherever the limestones are not too pure, as is mostly the case in North America; while in the portions of Europe in which chalk—an exceedingly pure limestone—is the country rock, "poor chalk land" is frequently spoken of.

But in the arid regions no such distinction is popularly made. This is natural since, as we have seen, lime carbonate is constantly accumulating in their soils, and, therefore, it is not to be expected that the connection with a limestone formation should make any material difference in their quality.

This leaching process is of such great importance, both theoretically and practically, as influencing the thriftiness of soils, and, therefore, the agricultural practice of the humid and arid regions respectively, that a somewhat detailed presentation and discussion of the facts is called for; the more as these have never, so far as I am aware, been definitely observed or placed on record heretofore.

For the study of this question an extended comparison of the composition of the soils of representative arid and humid regions is required; and I have, for this purpose, gathered together and tabulated for comparison, all the available analyses of soils from the humid and arid portions of the United States, respectively.

COMPARISON OF SOILS FROM THE ARID AND HUMID REGIONS OF THE UNITED STATES.

To give in detail the large number of analyses upon which the following table is based would exceed the proper limits of this paper. As the greater portion of them are in print in publications not difficult of access, references are given to the records from which the data have been derived; only as regards the soils of Washington and Montana, the data are still in manuscript only, and form part of the records remaining in the writer's hands since the regretable cessation of the Northern Transcontinental Survey, prosecuted from 1880 to 1883, under the auspices of the Northern Pacific Railroad.

SELECTION OF DATA FOR COMPARISON—METHODS OF ANALYSIS.

As it is absolutely essential that in making such comparisons the analyses should have been made by exactly the same methods, I have included in it exclusively those for which this condition is with certainty fulfilled, namely, the several series made under my own direction from 1857 to the present time, and those made in connection with the geological surveys of Kentucky and Arkansas (first under the direction of Dr. David Dale Owen, and since his death under that of others), mostly by Dr. Robert Peter, the veteran chemist of the Kentucky survey at this time. Some, of which the comparability in this respect is probable, but not certain, published in the reports of other states, have been omitted because of this uncertainty.

SOILS FROM CALCAREOUS AREAS OMITTED.

Another consideration has governed the omission from the present comparison of a large number of soils that have been analyzed on the same plan. It is plain that if we were to include such as have, in their origin, a more or less direct connection with calcareous formations, either as residuals still underlaid by such formations, or as alluvials and colluvials derived from the same, the climatic influences would be obscured and the comparison still further vitiated by the accident of the numerical proportion between the number of such soils and those derived from non-calcareous materials, that happened to have been chosen for examination. Tennessee forms a case in point. It happens that all of the seventeen soil analyses made for that state during the census work of 1880 are more or less directly connected with calcareous formations, which underlie the prominent agricultural subdivisions thus far studied. From this cause Tennessee is unrepresented in the list of states below; and for the same reason a very large proportion of Dr. Peter's analyses of Kentucky soils are thrown out, *e. g.*, the well-known "blue-grass region," and generally that portion of the state covered by limestone formations.

On the same ground, of one hundred and forty-one analyses of Arkansas soils by D. D. Owen and Dr. Peter, only thirty-eight could be admitted to comparison. In this case, as in that of Mississippi and Louisiana, the large proportion of "bottom soils" derived from the calcareous clays of the Port Hudson beds, and from the loess area, has necessitated the body of the exclusions.

In Mississippi the soils of the cretaceous and tertiary prairies, of the loess proper, and those of the heavy soils of the alluvial area (Yazoo bottom) that are directly derived from the Port Hudson clays, are excluded; but not those of the recent alluvium, nor those of the tributaries from the uplands. Thus out of one hundred and thirty analyses thirty-three have been excluded. The analyses of the brown loams underlying the loess, though somewhat influenced by the subjacent formation, are nevertheless retained.

Of twenty-five available analyses of Louisiana soils, seven are excluded because of their direct connection with the Port Hudson and loess materials.

Of 40 available analyses of Texas soils, all but 7 are from "prairie" areas known to be underlaid by calcareous materials. The seven forming the somewhat doubtful exception (because in part from areas underlaid by calcareous tertiaries) are from points lying both in the humid and arid portions of the state, and therefore would not make a fair showing for either. The same is true of the few analyses of soils from the Indian Territory.

Of 56 available analyses of Alabama soils, all but six, representing well-known "prairie" areas, enter into the averages.

All known analyses of Florida soils, seven in number, are included.

Of 60 analyses of Georgia soils, 17 representing the essentially calcareous areas of what is known as "Northwest Georgia"—palaeozoic terranes—are excluded from the comparison, together with three others from the tertiary region.

All available soil analyses from South Carolina are included. So also are those from North Carolina, except those made for the geological survey of the state, the method used in these analyses being unknown and apparently different from that adopted in the census work of 1880.

The same general system of selection and exclusion has, of course, been put in force on the available soil analyses from the arid regions; mainly represented thus far by California, Washington, and central Montana. As is well known to geologists, these are regions very deficient in limestone formations, so that it is difficult to obtain material for a home supply of lime for building and other purposes. It is true that the rock material of the cretaceous and tertiary beds covering large portions of these regions is often more or less calcareous, and would by disintegration yield a slightly calcareous average material. But the same is true of a large portion of the humid region in areas which, nevertheless, have not been ruled out from this comparison. Wherever it is known that a specially calcareous deposit is near at hand, and may have contributed an extra proportion of calcic carbonate, the analysis has been ruled out; and on the same ground as in the case of the soils of the lower Mississippi, where the old swamp (Port Hudson) beds have been an essential contributory factor, the corresponding soils from the troughs of the valley of California have been excluded. Thus of a total of 236 analyses of California soils, 38 have been excluded from the averages.

Out of 80 analyses of Washington soils, four showing unusual proportions of lime were ruled out on suspicion that there might be a special source of lime involved. In the rest the range is so steadily from a little below one to a little over two per cent., that there was no basis for a discrimination, the more as the country is destitute of limestones and, save at a few points, even of any obviously marly formations.

In the case of Montana, 14 out of 43 soils have been ruled out, mostly on suspicion of, but partly because of, known connection with limestone formations; as, *e. g.*, in the case of lands at the foot of the Big Snowies, a limestone range forming part of the northern rim of the Judith basin.

The rule thus having been applied, as impartially as possible, to the soils of both the humid and arid regions, I believe that the conclusions flowing from a discussion of the results of the comparison are entitled to as much weight as are those of any comparison based on large numbers of observations made, not with reference to the special point under consideration, but with a practical object of which the governing conditions were more or less uncertain and required to be ascertained by a process of elimination.

The table gives, first, the averages for each ingredient for each of the states represented, the number of analyses from which the averages are derived being given in each case. These averages are given separately for the states of the humid and the arid regions respectively; and at the base of each group the grand average is shown in two forms. The first gives the figures as derived from the aggregate number of soil analyses in each great group, being 466 for the humid and 313 for the arid, divided into the totals resulting from the summation of each ingredient for the whole, 466 and 313, respectively.

The second form is that in which the soils of each state are considered as representative of the general character of such state, as the result of intentional selection; such as actually occurred in the cases of those included in the census work of 1880. The figures given here are therefore the result of a summation of the state averages as such, and of their division by the number of states represented.

It may be cursorily noted here that while these two modes of presentation do change the figures a little, yet in either form the same general result is outlined with striking accuracy.

It will be noted that in some cases the averages for states are not all based upon the same number of analyses. This happens mostly because of omissions made in determinations, occurring most frequently in the case of the item "soluble silica." It must be understood that in the earlier work the importance of ascertaining this point in every case had not been thought of. Hence it is entirely wanting in the analyses representing Kentucky and Arkansas and in all the earlier work relating to Mississippi. This explains why in some cases the averages of the two first columns (insoluble residue and soluble silica) do not sum up correctly in the third column, which, where both determinations always have been made, should be the sum of the two preceding.

To amplify the evidence as much as possible there are also given three analyses from Colorado, New Mexico, and Utah, made for the purpose of ascertaining the probable success of sugar beets, and therefore, as it happens, representing characteristic "mesa" or plateau lands. These analyses were made in the laboratory of the California Experiment Station by Mr. Hubert P. Dyer, chemist to the Utah beet sugary near Lehi.

Below these is given the averages from nine soils analyzed at the Wyoming Experiment Station, and representing the surface soils of the six culture experiment stations of that state. The subsoils given in the same publication are omitted because some of them are manifestly in contact with calcareous formations, so that the lime average would be grossly exaggerated, as in the case of the soil from New Mexico, which has been excluded from comparison for the same apparent reason. Moreover, this series is not included in the averages of the three soils above, because of divergencies in the method of analysis. Nevertheless, the general results are precisely in line with the remainder of the averages for the arid region.

REFERENCES TO SOURCES OF DATA.

For the analyses of soils from the states of North and South Carolina, Georgia, Florida, and Alabama, Report of U. S. Census for 1880, vol. 6.

For the states of Mississippi, Louisiana, and Arkansas, *ibid.*, vol. 5; from reports of the respective geological surveys and reconnoissances, and partly from manuscript records, still unpublished.

For Kentucky, the reports of the Geological Survey of Kentucky from 1856 to the present time; analyses by Dr. Robert Peter.

For California, the several reports of the College of Agriculture and Experiment Station of the University of California from 1877 to the present time.

For Washington and Montana, the manuscript records of the Northern Transcontinental Survey from 1880 to 1883.

For Utah, New Mexico, and Colorado, manuscript record of work by Hubert P. Dyer, chemist to the Utah Sugar Company, Lehi, Utah.

For Wyoming, Bulletin No. 6 of the Wyoming Experiment Station, May, 1892.

Average composition of soils in the humid and arid regions of the United States.

Name of state.	No. of soils averaged.	Insoluble residue.	Soluble silica.	Total insoluble residue and soluble silica.	Potash.	Soda.	Lime.	Magnesia.	Brown oxide manganese.	Peroxide of iron.	Alumina.	Phosphoric acid.	Sulphuric acid.	Water and organic matter.	Total.	Hygroscopic moisture.	Temperature of absorption, C.	Soluble phosphoric acid.	Humus.	Carbonic acid.	Available inorganic matter.
North Carolina	20	81.627	3.505	85.133	.145	.057	.088	.080	.071	4.718	5.713	.118	.061	3.977	100.163	4.282	21.1	.....	.....	.....	.....
South Carolina	11	83.493	3.425	86.919	.123	.059	.114	.155	.083	2.771	5.709	.097	.108	3.899	100.039	4.228	23.6	.....	.....	.....	.....
Georgia	40	86.066	2.887	88.954	.150	.065	.076	.099	.090	2.751	4.018	.111	.096	3.619	100.029	3.541	17.0	.....	4.383	.....	.....
Florida	7	94.277	1.172	95.449	.101	.034	.091	.027	.077	.749	1.169	.091	.069	2.274	100.136	2.204	24.4	.....	.....	.....	.....
Alabama	50	81.576	4.893	86.469	.231	.073	.169	.210	.120	3.814	2.699	.134	.053	4.039	100.011	7.066	20.2	.....	.....	.....	.....
Mississippi	97	85.870	4.391	89.714	.276	.109	.145	.312	.137	2.643	4.069	.091	.029	3.331	100.176	5.410	15.4	.....	.680	.....	.....
Arkansas	38	.....	.....	88.539	.165	.056	.081	.430*	.205	3.099	3.511	.150	.045	3.704	99.931	2.473	.....	.....	.....	.....	.....
Kentucky	185	.....	.....	86.719	.199	.104	.081	.193	.197	6.008	3.523	.109	.038	3.691	100.862	1.845	.....	.....	.....	.....	.....
Louisiana	18	78.393	6.837	85.231	.290	.086	.163	.379	.153	4.543	5.667	.129	.087	3.480	100.261	6.656	24.5	.....	.....	.....	.....
Total for humid region.	466	84.031	4.212	87.687	.216	.091	.108	.225	.133	3.131	4.296	.113	.052	3.644	100.178	4.650	18.5	.....	2.39	.....	.....
Averages by states	....	84.472	3.873	88.126	.187	.071	.112	.209	.126	3.455	4.008	.114	.065	3.557	100.093	4.189	20.9	.....	2.53	.....	.....
California	198	67.882	8.960	76.842	.644	.277	1.075	1.488	.062	6.303	8.721	.083	.048	4.396	100.048	5.925	.....	.03	1.040	1.148	.48
Washington	76	75.021	3.673	78.696	.777	.249	1.378	1.171	.049	5.530	6.063	.173	.028	5.226	99.952	5.941	.....	.....	1.155	.403	4.67
Montana	39	66.141	6.235	72.376	1.005	.226	2.483	1.494	.057	4.459	7.145	.178	.029	7.133	99.935	8.712	.....	.....	3.321	2.398	1.82
Total for arid region.	313	70.565	7.266	76.135	.729	.264	1.362	1.411	.059	5.752	7.888	.117	.041	4.945	99.993	6.281	.....	.....	1.839	1.316	2.32
Averages by states	....	69.681	6.289	75.652	.825	.251	1.645	1.384	.056	5.431	7.309	.144	.035	5.585	99.978	6.859	.....	.....	1.830	1.316	2.32
Utah	1	79.20	4.70	83.90	.709	.404	1.237	.848	.019	7.770	1.477	.160	.003	3.707	100.232	.....	.....	.....	.....	.....	.....
New Mexico	1	63.20	7.32	70.52	.732	.176	*10.060	1.007	.020	4.031	2.560	.103	.082	3.197	99.849	CO^2 —7.360	.....	.....	.....	.....	.....
Colorado	1	69.61	11.12	80.73	.964	.113	.706	.845	.006	6.640	5.560	.090	.033	4.430	100.117	.....	.....	.....	.....	.....	.....
Average of the three	....	70.67	7.71	78.38	.801	.231	.971	.900	.015	6.147	3.199	.117	.039	3.778	100.099	.....	.....	.....	.....	.....	.....
Wyoming	9	75.79	2.45	78.24	.72	.47	2.67	1.45	.....	3.32	5.85	.18	.10	4.79	99.69	.....	.....	.....	.....	1.90	.....

* Omitted in the average.

LIME.

Considering in this table, first, the ingredient under discussion above, viz., lime, a glance at the columns for the two regions shows a surprising and evidently intrinsic and material difference, approximating in the average by totals to the proportion of 1 to 12; in the average by states, 1 to 14½. This difference is so great that no accidental errors in the selection or analysis of the soils can to any material degree weaken the overwhelming proof of the correctness of the inference drawn upon theoretical grounds, viz., that the soils of the arid regions must be richer in lime than those of the humid countries. For the differences in derivation would, in view of the prevalence of limestone formations in the humid regions concerned, produce exactly the reverse condition of things from that which is actually found to exist; and if further proof were needed it can readily be found in the detailed discussion of the analyses of the soils of the arid areas forming the contrast. This shows that, for instance, in Washington highly calcareous soils are directly derived from the black basaltic rocks; while similarly calcareous lands are found in California to be outcome of the decomposition of granites, diorites, and lavas.

It is not easy to overrate the importance of this feature of the soils of the arid region, as it is intimately connected with other theoretically and practically important facts which will be discussed later.

Now, if it be true, that "a limestone country is a rich country" in the humid regions, and, if, as the tables show, the soils of the arid regions are all calcareous to the extent to which that property serves its general purpose,* then it must also be true that when the deficiency of rainfall in the arid regions is supplied by irrigation, the soils of the arid regions should be exceptionally productive as compared with those of the regions of summer rains.

I think experience shows that this is strictly true, and that in the arid region "poor" soils are very much less common than in the humid climates. As farmers would express it, the land is "all marled" in its natural condition, and a smaller area can there, on the average, be made to sustain a family.

Is there not here a clue to the fact that has excited the surprise of many, viz., that arid or irrigation countries have in past times been the chosen abodes of dense populations, whether about the rock-hewn cities of Syria or in those of Arizona? Is it not true that the "desert" is a desert merely in appearance, and that the life-giving water brought by

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* The lime percentage usually mentioned in text-books as necessary to the "calcareous" character of a soil ("vigorous effervescence with acids") implying not less than 4 per cent. of the carbonate, is very much greater than is actually necessary to impart all the desirable and characteristic agricultural and vegetative features to soils that depend upon the action of lime. Very much less is, moreover, required for that purpose in sandy soils than in those which contain much clay. See Report of Tenth Census, vol. 5, page 64.

the hand of man is all that is needed to convert it into a land where milk and honey flow? According to recent experiments, even the shifting sands of the Sahara desert become productive when irrigated

UPLAND AND LOWLAND VEGETATION IN THE ARID AND HUMID REGIONS.

In the humid regions there is always a marked difference between the vegetation of uplands and lowlands, arising not merely from the difference in moisture supply, but evidently of a specific nature. When we discuss the characteristic plants in detail, it becomes obvious that it is lime vegetation that forms the characteristic difference in most cases; and by way of counter-proof we find that when the uplands are themselves of a calcareous nature, a part of the valley flora ascends into them. To mention one of many instances: The tulip tree (*Liriodendron*, Whitewood) is a lowland tree over the greater part of its area of occurrence; but in the loess or cane-hills area of the Southwest, as well as in the cretaceous (limestone) hill country of Mississippi, it is conspicuous in the uplands. The same is true of the black walnut, the linden, and many other trees and shrubs characteristic of limy soils.

In the arid region, on the contrary, the main difference observable in upland and lowland vegetation (outside of mountain influences) is entirely referable to moisture conditions; the proof being that so soon as the uplands are irrigated the lowland flora, so far as it is distinct, takes possession. This uniformity of upland and lowland vegetation is particularly conspicuous in the comparatively restricted floras of the Pacific northwest—eastern Oregon and Washington, and Montana, where one may travel for days over hill and dale and plains, all equally arid, with scarcely a change in the character of the flora, especially during the dry season. Both uplands and lowlands being nearly equally calcareous, there is no reason for any material difference.

FORMATION OF CALCAREOUS HARDPAN IN SUBSOILS.

As stated above, subsoils are in all ordinary cases richer in lime compounds than the overlying surface soil, owing to the solubility of lime carbonate in the soil water, which, being followed by air when rain ceases, gradually deposits the lime in the lower layers of the arable stratum, by the well-understood process of aëration.

In humid climates, however, the frequent rains, so very variable in amount, rarely allow of the accumulation of very large amounts of this substance at a particular depth. Hence, while in such regions (the prairies of Mississippi and Louisiana) we often find, in soils overlying calcareous strata, a formation of whitish concretions (commonly known as "white gravel") of lime carbonate, yet the formation of continuous layers or sheets of subsoil cemented by lime is not frequent.

In the arid regions, on the contrary, the limited rainfall usually penetrates only to a relatively slight depth—a few feet—whence the water afterwards re-ascends, to be dissipated by evaporation. Thus the lime carbonate dissolved in its descent gradually accumulates within a very limited thickness of soil, and chiefly at the lowest point usually reached by the moisture. Concurrently, the diffused clay brought down by each rain stops at or near the same level; and both substances combine to form a mechanical union into a subsoil layer of "hardpan," the cement of which is lime carbonate, and which therefore effervesces (sizzes) to a greater or less degree when touched with a drop of acid.

These hardpan sheets are usually more or less discontinuous, the areas occupied by them being commonly of a rounded or oblong shape, and lowest in the middle. In case of unusually copious rains, or when irrigated, they may frequently be recognized by the formation of temporary ponds, deepest in the middle or axis of the sheet. Such stagnation of water serves ultimately, of course, to increase the hardness and thickness of the hardpan sheet, by the further dissolution of lime during the fermentation of vegetable matter that always occurs in stagnant water, and its subsequent deposition upon the concrete already formed.

Such hardpan areas are familiar to cultivators in the arid regions throughout the world; from the Rocky Mountains to the Pacific coast, as well as in northwest India, where the "kankar" is a formidable obstacle to the cultivation of lands otherwise very rich and capable of profuse production. In India it seems to assume, more frequently than in California and Arizona, the form of a hard crystalline, though very impure limestone, which no tool short of a crowbar can deal with. Of course roots cannot penetrate it, and after irrigation the water stands on the lands underlaid by it, drowning out what otherwise might have been a fair crop. The trouble is experienced somewhat in California, in some portions of the Great Valley, where soils of a fine silty character prevail; less often in the more coarsely sandy lands. In the heavy clay lands (adobe) of the lower grounds, such accumulations of lime carbonate are also quite common, as might be expected; but, contrary to expectation, they are usually less hard and offer less obstruction to roots and to the penetration of water than is the case in the silt soils. Moreover, the lime hardpan in these clay soils crumbles very rapidly upon exposure to the air, or thorough drainage, and is, therefore, less injurious, and less difficult to deal with than in other soils.

MAGNESIA CONTENTS OF SOILS IN THE ARID AND HUMID REGIONS.

While the differences in respect to the proportions of lime are the most prominent and decided, yet the related substance, magnesia, shows also a very marked and constant difference as between the soils of the humid and arid regions. It will be observed that the general average for magnesia in the soils of the Atlantic slope is about double that of lime; Florida being the only state in which the average (of seven analyses) is lower for magnesia than for lime. In the arid region, on the contrary, magnesia on the general average is nearly the same as lime; in the average by states, slightly above it; thus bringing the ratio for the two regions for magnesia up to one to six or seven. This also is so decisive a showing that no accident could bring it about. We must conclude that climatic influences have dealt with magnesia similarly as with lime, which from the standpoint of the chemist is just what might be expected, since magnesia carbonate behaves very much like that of lime toward carbonated waters. It is not, however, known to exert any peculiar influence upon soils or plant nutrition; and hence, while its presence in the soils of the arid regions is corroborative of the evidence concerning lime, it is not of similar practical significance.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE "INSOLUBLE RESIDUE."

Remembering, in discussing the facts shown by the table, that the fundamental difference between the régime of the humid and arid regions is the presence of an almost continuous leaching process, in which the carbonated water of the soil is the solvent; remembering, also, that the least soluble portion of rocks and soils is quartz or silica (sand, as usually understood), it would be predicable that this ingredient should in the humid region be found to be more abundant in soils than in the arid. This portion is represented by the "insoluble residue" of the table.

Inspection shows that both in the averages of the single states, and in both of the general averages, this difference between the soils of the humid and the arid regions of the United States is strongly pronounced; the ratio being substantially as 70 per cent. in the arid region to 84 per cent. in the humid.

We must then conclude that the leaching process must have influenced materially other soil ingredients than lime, which have remained behind in such amounts as to depress the percentage of insoluble residue in the soils. It remains to be shown what are the substances so retained.

SOLUBLE SILICA AND ALUMINA.

The ingredient most nearly correlated with the insoluble residue is the silica which remains behind with it when the acid with which the soil has been treated preparatory to analysis is evaporated to dryness. The gelatinous or pulverulent silica set free by the acid from the soil silicates being thus rendered insoluble in acid and water, it is separated from the really insoluble and undecomposed minerals by boiling with a strong solution of sodic carbonate, to which, after boiling, a few drops of strong caustic soda lye have been added in order to prevent the re-precipitation of part of the soluble silica. The amount of the latter is obviously the measure of the extent to which the soil silicates have been decomposed in the treatment with acid.

The most prominent of these is usually supposed to be clay—the hydrous silicate of alumina that in its purest condition forms kaolinite or porcelain earth. Any alumina found in the usual course of soil analysis is generally referred to this mineral, which contains silica and alumina nearly in the proportion of 46 to 40.

In very many cases, however, the reference of these two ingredients to clay is manifestly unjustified. This is clearly so when (as not unfrequently happens) the amount of alumina found exceeds that which would form clay with the ascertained percentage of soluble silica; it is almost as certainly so when, in addition to the alumina, other bases (notably potash, lime, and magnesia) are found in proportions which preclude their being in combination with any other acidic compounds present. The only possible inference in such cases is that these bases, together with at least a portion of the alumina, are present in the form of hydros, and therefore easily decomposable silicates, or zeolites.

The subjoined analysis of a clay obtained in the usual process of mechanical soil analysis (by precipitating with common salt the turbid water remaining after 24 hours subsidence in a column of 200 millimeters) from a very generalized soil of northern Mississippi, shows one of the many cases in which the numerical ratios of the several ingredients are incompatible with the assumption that silica and alumina are present in combination as clay (kaolinite) only:

Insoluble matter	15. 96
Soluble silica	33. 10
Potash (K_2O)	1. 47
Soda (Na_2O)	1. 70
Lime (CaO)	. 09
Magnesia (MgO)	1. 33
Br. ox. of manganese (Mn_3O_4)	. 30
Peroxide of iron (Fe_2O_3)	18. 76
Aluminia (Al_2O_3)	18. 19
Phosphoric acid (P_2O_5)	. 18
Sulphuric acid (SO_3)	. 06
Carbonic acid (CO_2)	. 00
Water and organic matter	9. 00
Total	100. 14

If in this case we assign all the alumnia to silica, as required for the composition of kaolinite or true clay, there yet remains a trifle over twelve (12.17) per cent. of silica to be allotted to the other bases present. Deducting from this the ascertained amount of silica soluble in sodic carbonate, pre-existing in the raw material, (.38 per cent.) we come to 11.79 per cent. as the amount of silica which must have been in combinations other than kaolinite, viz., hydrous silicates, or soil zeolites, formed either with the bases other than aluminia shown in the analysis, or, more probably, perhaps containing some of the aluminia itself in essential combination.

We are thus enabled to obtain from the determination of the soluble silica an estimate of the extent to which these soil zeolites, that form so important a portion of the soil in being the repositories of the reserve of more or less available mineral plant food, are present in the soils of the several regions. A glance at the table shows that the general average of soluble silica is very much greater in the soils of the arid regions than in those of the humid, approximating one to two in favor of the arid division.

But looking at the details of the several states, we find that on the arid side Washington has a relatively low figure for soluble silica, that in the average, however, is overborne by the high figures for California and Montana. The explanation of this fact probably lies in the derivation of the majority of the Washington soils examined, from lake deposits brought down gradually from the humid region at the heads of the Columbia drainage, where sandy beds are very prevalent; while the country rock—the basaltic eruptives—are very basic, and moreover slow to disintegrate. In California and Montana the rocks are infinitely varied, and the general outcome of their weathering is plainly a predominance of complex hydrous silicates in the soils, as compared with humid regions.

ZEOLITES ARE REPOSITORIES OF PLANT FOOD,

Nor should this be a matter of surprise when we consider the agencies which are brought to bear upon the soils of the arid regions with so much greater intensity than can be the case where the solutions resulting from the weathering process are continually removed as fast as formed, by the continuous leaching effect of atmospheric waters. In the soils of regions where summer rains are insignificant or wanting, these solutions not only remain, but are concentrated by evaporation to a point that, in the nature of the case, can never be reached in humid climates. Prominent among these soluble ingredients are the silicates and carbonates of the two alkalies, potash and soda. The former, when filtered through a soil containing the carbonates of lime and magnesia, will soon be transformed into complex silicates, in which potash takes precedence of soda, and which, existing in a very finely divided (at the outset in a gelatinous) condition, serve as an ever-ready reservoir to catch and store the lingering alkalies as they are set free from the rocks, whether in the form of soluble silicates or carbonates. The latter have another still important effect: in the concentrated form at least, they, themselves, are effective in decomposing silicate minerals refractory to milder agencies, such as calcic carbonate solutions; and thus the more decomposed state in which we find the soil minerals of the arid regions is intelligible on that ground alone.

But it must not be forgotten that lime carbonate, though less effective than the corresponding alkali solutions, nevertheless is known to produce, by long continued action, chemical effects similar to those that are more quickly and energetically brought about by the action of caustic lime. In fact, the agricultural effects of "liming" are only in degree different from those produced by marling with finely pulverized carbonate; and in nature the same relation is strikingly exemplified in the peculiarly black humus that is characteristic of calcareous soils, but which can be much more quickly formed under the influence of caustic lime on peaty soils.

In the analysis of silicates we employ caustic lime for the setting-free of the alkalies and the formation of easily decomposable silicates, by igniting the mixture; but the carbonate will slowly produce a similar change, both in the laboratory and in the soils in which it is constantly present. This is strikingly seen when we contrast the analyses of calcareous clay soils of the humid region with the corresponding non-calcareous ones of the same. In the former the proportions of dissolved silica and alumina are almost invariably much greater than in the latter, so far as such comparisons are practicable without assured absolute identity of materials. That is, calcareous clays or clay soils are so sure to yield to the analyst large precipitates of alumina, that experience teaches him to employ smaller amounts for analysis than he would of non-calcareous materials, in order to avoid unmanagebly large bulks of aluminic hydrate. It is but rarely that even the heaviest non-calcareous soils yield to the acid usually used in soil analysis more than 10 per cent. of alumina; while heavy calcareous clay (prairie) soils commonly yield between 13 and 20 per cent.* It would be interesting to verify this relation by artificial digestions of one and the same clays with calcic carbonate at high temperatures, as it must always be extremely difficult to insure absolute identity of all other conditions in the natural materials.

In most of these cases, what is true of alumina is also true of the soluble silica. But since the latter is constantly liable to be dissolved out by solutions of carbonated alkalies, it is not surprising that this relation is not always shown. What is shown in very many cases is that, since the amount of alumina dissolved greatly exceeds that of soluble silica, a portion of the latter must be present in a different form from that of clay (kaolinite); the only choice being between that of complex hydrous silicates (none of which, however, could contain as large a percentage of alumina as clay itself) and aluminic hydrate. The latter is alone capable of explaining the presence of more alumina than silica in easily soluble form; and the visible occurrence of

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*Report of the Tenth Census, vols. 5 and 6; see especially the analyses of soils from Mississippi and Alabama. Also the Reports of the California Experiment Station.

"gibbsite" in modern formations renders this a perfectly simple and acceptable explanation. Since this mineral is known to be incapable of crystallization, we are, moreover, led to the presumption that it will, as a rule, be found in the finest portions of the soil, viz., in the "clay" of mechanical analysis. What part it may take in modifying the physical properties of the soil, we can thus far only conjecture; in two conspicuous cases of this kind, from Mississippi and California,* the soil material is characterized by such extraordinary tenacity and adhesiveness as to render tillage almost practically impossible, while the natural plant growth is very scanty. No corresponding extreme physical condition is, however, exhibited by the soils from Washington and Oregon of which analyses are given on page 14, in which an excess of alumina over soluble silica is likewise shown.

There is no very obvious reason, from the chemical standpoint, why iron, that is, ferric hydrate or iron rust, should be more abundant in the soils of the arid regions, as the averages given in the table suggest; moreover, the fact does not impress itself upon the eye, since the whitish or grayish tints are by far more common in the arid than in the humid regions of the United States at least. The California average is considerably influenced by the very highly ferruginous soils from the foothills of the Sierra Nevada; that of Oregon by the black, highly ferruginous country rock, from which they are partly derived. The average for Montana is not higher than that of three states of the humid region, and less than that of Kentucky. We might imagine a cause for depletion of iron in the soils of the humid areas in the frequency with which humid moisture and high temperature will during the summers concur toward the bringing about of a reducing process in the soil, which by getting the iron into proto-carbonate solution would make it liable to be leached into the subsoil, as is frequently the case; yet the resulting "black gravel" or bog ore, in its various forms, is of not unfrequent occurrence in the arid regions also. I therefore am not satisfied that a constant difference due to climatic conditions is shown by the data thus far at command.

An unexpected and apparently well-defined contrary relation appears to be shown as regards the related metal manganese; the average percentage of which is in all cases less in the arid than in the humid region, on the average over one to two. The cause of this relation is altogether obscure; it is too well maintained to be accidental. In any it is, so far as we know, of no consequence to vegetation.

As regards that highly important soil ingredient, phosphoric acid, the indication in the table that there is no characteristic difference in the average contents in soils of the arid and humid regions, respectively,

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*These cases are Nos. 208 and 207, Mississippi (Rep. Tenth Census, vol. 5, p. 256), in which the soluble silica and alumina stand in the ratio of about seven to over twenty; and No. 703, California (*ibid.*, vol. 6, p. 712), in which the ratio is as nine to nearly sixteen. See also the table above, page 14.

is doubtless correct. This substance is so tenaciously retained by all soils that there is no conceivable reason why there should be any material influence exerted upon its quantity by leaching, or by any of the differences in the process of weathering that are known to exist between the two climatic regions. Moreover, it is obvious that the average for the arid region is made up out of very widely divergent data; that of California exceptionally low (lower than any of those for the humid regions), while those for Washington and Montana are exceptionally high. The latter is due to country rocks showing abundance of microscopic crystals of apatite, which in some cases raise the contents of the soils in phosphoric acid to nearly twice the average given for the states.

The forecast that for most California soils, fertilization with phosphates is of exceptional importance, has already been abundantly confirmed by experience.

The showing made by the table regarding sulphuric acid, that sulphates are less abundant in the soils of the arid than that of the humid region, is surprising in view of the prevalence of sulphates of the alkalies, which show themselves in the form of efflorescence but too frequently. It is true that the majority of such alkali soils have, on account of their exceptional and local nature (and usually heavy lime contents), been excluded from the comparison; otherwise the showing would have been quite the reverse. No significance attaches, therefore, to these figures.

POTASH AND SODA IN THE SOILS OF THE ARID AND HUMID REGIONS.

The compounds of the alkali metals, potassium and sodium, being on the whole much more soluble in water, even without the concurrence of carbonic acid, than those of calcium and magnesium, the leaching process that creates such pronounced differences in the case of the two earths must affect the alkali compounds very materially. Comparison of the soils of the two regions in this respect shows, indeed, very great differences in the average contents of potash and soda. For potash the ratio is .216 to .725 per cent. on the general average, and .187 to .825 per cent. in the average by states; for soda, .091 per cent. to .264 per cent. on the general average, and .071 per cent. to .251 per cent. in the average by states. For both, therefore, the general average ratio is as one to between three and four for the humid as against the arid region.

It is curious that an approximation to the ratio of one to three, or somewhat less, is maintained in the average proportion of soda to potash in both regions; but this does not by any means hold good in detail, very high potash percentages being often accompanied by figures for soda very much below the above ratio. This is the result of an important difference in the chemical behavior of the two alkalies, which must be considered somewhat in detail in order to obtain a clear conception of the process by which alkali soils are formed.

The process of "kaolinization," being that by which clays are formed out of feldspathic minerals and rocks such as granite, diorite, trachyte, etc., results in the simultaneous formation of solutions of carbonates and silicates of potash and soda. These coming in contact with the corresponding compounds of lime and magnesia, also common products of rock decomposition, are partly taken up by the latter, forming complex, insoluble, hydrous silicates (zeolites). In these, however, potash whenever present takes precedence of soda; so that, when a solution of a potash compound is brought in contact with a zeolite containing much soda, the latter is partially or wholly displaced and, being soluble, tends to be washed away by the rainfall into the country drainage. Hence potash, fortunately for agriculture, is tenaciously held by soils, while soda accumulates only where the rainfall or drainage is insufficient to effect proper leaching, and in that case manifests itself in the formation of what is popularly known as alkali soils; namely, those in which a notable amount of soluble salts exist, and are kept in circulation by the alternation of rainfall and evaporation; the latter causing the salts to accumulate at the surface and to manifest themselves in the form of saline crusts or efflorescences.

The designation of alkali soils is, however, popularly bestowed somewhat indiscriminately upon two classes of lands of very different origin, and requiring for their reclamation quite different treatment. In both cases it is mainly the salts of the alkalies—potash and soda—that imbue the soil and tend to injure vegetation. But when we have to deal with seashore lands that owe their saline contents only to the more or less continuous flooding with salt or brackish water, the conditions differ materially from those prevailing in the case of the true alkali soils, which owe their contents of salts to the scantiness of the rainfall, as heretofore explained.

In the former case, that of saline lands, it is chiefly common salt (chloride of sodium) with some bittern (chlorides and sulphates of calcium and magnesium) that forms the soluble impregnation, which is, of course, practically independent of climatic conditions. In the latter, while common salt is also commonly present, the most abundant is usually Glauber's salt (sulphate of soda), and with it very frequently, as the least welcome ingredient, carbonate of soda (sal soda). According to chemical laws the presence of the latter substance excludes, practically, the earthy salts classed above as bittern.

The saline shore lands, being practically independent of climatic influences, lie outside of the limits of this paper.

Alkali lands are a characteristic feature of all regions of scanty rainfall, and are found on all the continents, in Europe, in a portion of the Hungarian lowlands, and in a few localities of Mediterranean Spain. It is true that occasionally we find in the humid regions limited areas to which salts of various kinds are currently supplied from adjacent saline formations, as may be seen at some points in southern Mississippi and northern Louisiana. But such phenomena are entirely local and do not extend far from the source of supply, because the soluble salts are soon washed into the country drainage by the abundant rains.

In the arid regions, on the contrary, the substances composing the alkali salts are not only retained in their first soluble form, but by their continued presence influence profoundly the processes of soil formation in several ways.

In the accumulation of alkali salts of course much depends upon the nature of the soil; for it is obvious that in very porous soils the leaching-out can occur much more readily than in those that permit of but very slow percolation, so that a rain may chiefly run off from the surface and cease before even an approach to a complete downward penetration can have occurred. It is therefore a well-known fact that alkali is most troublesome in the heavier (adobe) lands; and as these are apt, in addition, to coincide with the lower ground, toward which the soluble salts are naturally carried with the seepage, it is not uncommonly found impracticable to cultivate these extremely rich lands without special methods tending either to diminish the alkali itself, or at least to prevent its accumulation at the surface, where its most injurious effects are produced.

It need hardly be said that, special qualities of soil apart, the alkali salts decrease as hills or mountains are approached, where increased slopes, and usually pervious soils, combine to permit of their leaching-out with even a relatively scanty rainfall. And inasmuch as ordinarily the rainfall increases rapidly with elevation, everything concurs to prevent the accumulation of alkali in mountainous or even hilly regions. High-lying plains or plateaus, however, do not by any means necessarily share this exemption, as is well illustrated in the case of the great interior plateaus of America and Asia.

THE ALKALI LANDS OF THE ARID REGIONS.

CLIMATIC LIMITATIONS OF ALKALI LANDS.

CALIFORNIA.

The question concerning the amount of rainfall under which alkali salts can be retained by the soil to a noticeable and injurious extent, can best perhaps be investigated in California, where the eastern portion of the Great Valley constitutes a region of very regularly varied rainfall; ranging from an annual mean of 34.60 inches at Redding on the north to (usually) less than 6 inches at Bakersfield on the south. The following table shows the decrease of rainfall to southward for a number of principal points in the valley:

Table of rainfall on the east side of the great valley of California.

Station.	Rainfall.	Station.	Rainfall.
	Inches.		*Inches.*
Redding	34.60	Lathrop	11.88
Red Bluff	23.79	Modesto	9.57
Chico	20.91	Merced	10.30
Nicolaus	18.55	Fresno	9.02
Sacramento	19.80	Tulare	7.00
Galt	16.72	Bakersfield	6.08
Stockton	13.18		

Apart from the decrease of rainfall to southward there is also a diminution from the eastern border of the valley toward the axis, and at some points even to the foot of the Coast Range on the western border. Thus Chico, on the east border, has nearly 21 inches; Orland, in the same latitude, but on the western edge of the valley, 16 inches. Marysville, on the east, 18.9; Colusa, in the axis, 16.24; Williams, on the west, 13.32 only. Tehama, only 10 miles south from Red Bluff, has not quite 16 inches against 23.79 at the former place. Of course, local conditions with respect to prevailing air currents have much to do with discrepancies, which, however, do not invalidate the general conclusions.

Roughly speaking, it may be said that the increase of alkali runs parallel with the decrease of rainfall in the valley; it is at its maximum near the south end, at its minimum near the north end, which, in fact, it does not reach. So far as its prevalence to an injurious extent is concerned, it practically ends, east of the Sacramento River, at or near the city of Sacramento, with an average rainfall of nearly 20 inches. Here the proximity to the base of the Sierra foothills exerts a disturbing influence, for we find at Marysville, forty miles farther to northward, but also farther out in the valley, only 18.9 inches. Local conditions prevent the accumulation of alkali salts east of the Sacramento River in this latitude; but immediately across, on the west side, all the heavier lands are alkaline, and with a rainfall of about 16 inches so continue, decreasingly, nearly to the head of the valley near Tehama.

To southward in the San Joaquin Valley, likewise, there is a general increase of alkali in the soil to westward, and in some regions clear to the foot of the coast range. The reason is, in part, the scanty drainage from that range, and the fact that the (tertiary) beds forming the immediate slopes are charged with both alkaline and earthy salts, and thus combine to increase the saline contents of the soils independently of climatic conditions; so that even the waters of many streams are in summer undrinkable. From similar causes limited alkali areas exist locally even near the coast, where the rainfall is in excess of 20 inches.

While, therefore, it can not be rigorously said that a certain rainfall conditions in all cases the alkalinity or non-alkalinity of soils, it certainly appears that in California, at least, 20 inches of rainfall is the upper limit beyond which the retention of any considerable amount of soluble salts in the soil becomes impossible under ordinary conditions of soil and drainage; while below that limit the degree of alkalinity is dependent more or less upon local conditions as well as soil texture, and may or may not reach the point at which these salts become of serious import to agriculture.

OREGON AND WASHINGTON.

If we extend the inquiry to other regions, notably to eastern Oregon and Washington on the north, where the climatic régime is similar to that of the "Franciscan" region of California, modified mainly by the greater cold of winter; we still find the same rule to hold good. There also the bulk of the rain or snow falls in the six months from November to April, inclusive, the rest of the year being practically rainless so far as any efficiency toward the leaching-out of soluble soil ingredients is concerned. This is especially true of the portions of these states lying between the Cascade Range on the west and the western branch of the Rocky Mountains (the Coeur d'Alene ranges) on the east, the Spokane River on the north, and the Blue Mountains on the south; excepting, of course, that portion which, on account of its proximity to the eastern chain, already enjoys a proportionally increased rainfall (to wit, the Palouse and Walla Walla country), and like northern California can produce annual crops without irrigation. Perhaps there is no part of the United States so severely afflicted with an excess of alkali salts near the surface as is the southern portion of what is known as the "Bend" country in Washington (Great Plain of the Columbia), with its lakes and streams of alkali water. Yet the northern half of the region is not only well suited to agriculture, but is actually rendered more so, in part, by the presence of a moderate amount of alkali salts. For the rainfall of this region we as yet have no data except the popular statement that it is awfully dry in the alkali region of the southern portion; while an increase toward the north must, apart from the successful cultivation, be inferred from the increase of timber as we approach the Spokane, and the fact that beyond that stream pine forest at once sets in. The precipitation at Fort Spokane, not far from the junction of the river with the Columbia, is, however, only about twelve inches; at Ellensburg, on the upper Yakima (west of the Columbia and farther to southward), nine inches; and, judging from the character of the vegetation, there is even less on the lower Yakima. Throughout this region alkaline efflorescences occur on most of the lower lands; while the rolling lands, owing to the pervious (silty) character of the soils, are generally free from any noticeable taint. Fort Simcoe, lying to southward at the northern foot of the partly wooded range which borders the Columbia River to northward of The Dalles, has over 13 inches, doubtless on account of that proximity; but to eastward the forest soon terminates and the range abuts on the Yakima plain, completely bare of tree growth and largely even of shrubs.

CENTRAL MONTANA.

With a rainfall ranging mostly between 7 and 14 inches, central Montana affords an interesting field of study in respect to the limitation of alkali by the amount of rainfall. Here the city of Helena occupies nearly the same relative position toward the Rocky Mountains as does Sacramento toward the Sierra Nevada, and the rainfall of the two cities is almost identical, being close to 20 inches. Owing to the location on a slope, no alkali appears within the city; but, as at Sacramento, it comes to the surface in the trough of the plain, to northward, and with decreasing rainfall becomes more and more conspicuous and troublesome as we descend the Missouri toward Fort Benton; the maximum being reached (together with the minimum of rainfall, so far as known—6.95 inches) in the region of about Fort Shaw, on Sun River, a western tributary of the Missouri. Here again, the perviousness of the silty soils makes the existence of alkali salts less apparent on the surface, but it becomes disagreeably obvious in the water of the springs, lakelets, and small streams of the region. East of the Missouri, the several groups and chains of mountains surrounding the Judith Basin modify the conditions of precipitation to a considerable, but not as yet accurately recorded, extent, leaving the northern part of the basin almost free from alkali land; but the southern portion, as well as the slopes toward the valley of the Musselshell River, are scarcely anywhere entirely free from the alkali taint. Toward the Yellowstone drainage area there is a gradual decrease of salts, and in the Yellowstone Valley itself alkali ceases to be a matter of practical interest.

These examples may suffice to show that while the presence of alkali is dependent upon a certain deficiency of rainfall, yet that fact alone does not necessarily imply its presence to any practically important extent, the greater or less perviousness of the soil and of the substrata, as well as a certain slope of the surface, being effectual in counteracting the accumulation. Nevertheless, as the table of soil composition shows, such deficiency remains potent everywhere in bringing about the main characteristics of the soils of the arid region, to wit., high percentages of lime, magnesia, and potash, and, relatively, of soda.

INDIA.

In India we find, in the Indo-Gangetic plain, a large area in which alkali (reh) is more or less troublesome to cultivation; extending all the way from the Indus and the Arabian Sea to a little beyond the Ganges, and from the Gulf of Cutch on the south to Afghanistan on the north, including all of Sind, Rajputana, the plains of the Punjab, the Northwest Provinces, and part of Oudh, to within a short distance of the

Himalaya ranges, incuding Lahore. Within this vast region the rainfall varies from a minimum of 4.3 inches at Jacobabad, on the Afghan frontier beyond the Indus, to over 30 at Cawnpore on the Ganges. We have but very scanty data as to the extent to which alkali salts prevail to an injurious extent within this area; all the provinces mentioned above are reported as suffering from "reh" more or less; but singularly enough the one region in which the evil has caused the appointment of a government commission to investigate its causes and remedies is the one, which, from the amount of rainfall, one would have supposed to be exempt from alkaline efflorescences. This is the country bordering upon the rivers Jumna and Ganges, and including the important cities of Delhi, Meerut, Agra, and Cawnpore. It is doubtless because of this fact, and of the high value of the land created by the extensive irrigation canals deriving their water from the two rivers, that the subject has here attracted such attention. The minimum rainfall occurs at Aligarh (24.3 inches), with 28.5 at Meerut and 27.6 at Delhi on the north, 26.5 at Agra and 26.7 at Etawah on the south. All these figures are materially above what in the arid region of North America appears to be the upper limit permitting of alkali efflorescences, viz., 20 inches or thereabouts; and the question as to the cause of this difference is of considerable interest, the more as no complaints of trouble with "reh" seem to come from the Deccan in southern India, where the same average rainfall of 24 to 30 inches prevails.

A study of the distribution of the rains through the year seems to account for the inefficacy of the rains in leaching the soil of the Northwest Provinces of its surplus salts. Unlike the "Franciscan" type of climate, in which nearly all the rainfall is concentrated within a consecutive period of six months, during which the soil is constantly kept wet enough to permit of percolation downward, the rains of northwest India fall more or less in all months of the year save November, but usually in such small amounts that no percolation is brought about, save that in the months of July and August nearly half of the annual precipitation comes down in torrential form, ill calculated to produce more than a wetting of the soil to a depth whence capillary rise will again carry the soluble salts to the surface. In the Deccan (south-central India) the distribution of the rains is less abrupt, keeping up more or less from March to December, inclusive, and with fewer torrential downpours. How little the latter can do towards removing the alkali salts is strikingly apparent even in Washington and Montana, where summer thunderstorms sometimes cause a sudden rise of the streams, quickly followed by dry stream beds. Such rains are as powerless to act upon the alkali in the soil as are the often repeated attempts to remove even the superficial efflorescences by quick and brief flooding. The first touch of the water dissolves the salts and the dry soil beneath instantly absorbs the solution, leaving the bulk of the water to flow by uselessly.

While to this extent the occurrence of alkali salts in India differs somewhat from that in North America, all the rest of the characteristics of the "reh-plague" are the same in both countries, and, so far as data are available, everywhere in the world. Unfortunately, the records even of the geological survey of India supply but scanty details in regard to the facts, although a good deal of discussion is had, from which we glean cursorily the main features of the case. The calcareous nature of the "reh" soils and their tendency to form hardpan or "kankar" which aggravates the evil, are referred to in connection with the leaching-out of the carbonate of lime from the higher slopes. The fact that the bottom water is frequently charged with salts, while deeper wells are free from any unusual taint, is mentioned in connection with the effects of irrigation; the undoubted fact that irrigation has increased the reh area is referred to, but the connection with the high-lying canals is called in question, because (as stated) no sensible dilution of the soil water has apparently taken place. Those who are familiar with the corresponding results of an exactly similar situation in California will hardly be disposed to concur in this doubt. As regards composition, also, the exact substances constantly found in our arid regions are mentioned; only considerably greater stress is laid upon the occurrence of nitrates, and nitrate of lime is mentioned as a possible good antidote for the carbonate of soda. It is not easy to see, from our point of view, how a sufficient amount of so expensive a salt should be procured for practical purposes, and why the cheap and abundant sulphate (gypsum) is not preferred in the recommendation.

ALKALI LAND OF OTHER COUNTRIES.

Turning to other countries of notably deficient rainfall from which data in point are available, we find in Egypt, Arabia, Syria, and Persia, as well as in the Aralo-Caspian plains, to the northern borders of Afghanistan, a state of things quite analogous to that of the arid regions of North America and India. Soils of extraordinary and lasting fertility when irrigated; a frequent mention of calcareous hardpan or tufa on the part of observant travelers; saline efflorescences as obstacles to cultivation; saline bottom waters, barely drinkable, in the shallow wells which alone the natives have found energy enough to dig; these are matters of constant mention, but too frequently attributed to the evaporation of the supposed salt-water basins. The climatic data available from these countries are mostly too scanty to determine what, in each of them, is the limit of rainfall beyond which alkaline salts cease to become apparent on the surface. It is interesting to note, in examining the records, how nearly the seasonal distribution and amount of rain credited to Jerusalem agrees with the "Franciscan" climate of central California; about 22 inches, falling from November to April, inclusive, enabling crops to grow without irrigation and preventing the accumulation of alkali salts to any injurious extent.

I am not aware that the subject of alkali lands, and the conditions of their existence and reclamation, have attracted the attention of the French colonies on the African coast quite as much as the manifest importance of the subject would seem to justify. The "shotts" on the northern edge of the desert seem to be regarded as hopeless alkali sinks only, from which to obtain soda for technical uses, as is also done in Fezzan.

Pretty much the same indifference appears even in Europe, in the Hungarian plain, where the gathering of "shekso" or crude soda, rather than cultivation, seems to be considered the destiny of the alkali lands.

COMPOSITION OF ALKALI SALTS IN DIFFERENT REGIONS.

In order to show the nature and possible functions of the alkali salts in soils I give below a table of analyses, selected from a large number, to show the great variety, as well as certain coincidences of composition, wherever found.

Composition of the soluble alkali in foreign localities.

NOTE.—To facilitate comparison, all the analytical data given in the following tables have been recalculated so as to show the composition of the soluble portion of the efflorescences, exclusive of gypsum where present. In many cases potash, nitrates, and phosphates were doubtless present but were overlooked.

Compounds.	Europe.		Asia.					Africa.			Australia.	
	Hungarian Plain, "szekso."		Plain of the Araxes.			Aden, "hurka."*	India, "reh."	Egypt, "trona."		Fezzan, "trona."	Bendigo, "alkali."†	
	Kalocsa.	Debreczin.										
Potassium sulphate (K_2SO_4)							11.1				1.28	1.63
Sodium sulphate (Na_2SO_4)	.2	1.6	10.4	18.2	15.5		7.0	23.6	38.3	.6	40.05	
Sodium carbonate (Na_2CO_3)	48.1	92.5	14.7	12.1	69.0	67.2	79.0	28.2	47.7	98.7		
Sodium chloride (NaCl)	51.7	4.4	74.6	69.7	15.5	32.8	2.9	48.2	14.0	.7	47.47	81.88
Sodium phosphate (Na_3PO_4)		1.5										
Magnesium sulphate ($MgSO_4$)											11.20	9.86
Magnesium chloride ($MgCl_2$)												6.73
Total	100.00	100.00	99.7	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.10

* Also called "kara," *i. e.*, "black alkali."

† Bulletin No. 14, Department of Agriculture, Victoria, page 18.

Composition of alkali in different states.

Ingredients.	California.									Washington.			
	Merced Co., Merced Bottom.	San Joaquin Co., Overhiser's.	Tulare county.			Kern Co., Kern Island.	Los Angeles Co., Mohave.	San Bernardino Co., Hunt's Lane.	Orange Co., Westminster.	Yakima county, 2 miles west of Yakima City, on Atahnam Creek.	Kittitas Co., Kittitas Valley, on Cherry Creek.	Whitman county, Lake Creek Bottom.	Spokane county, 3 miles southwest of Cottonwood Springs.
			Goshen.	Visalia.	Experiment station.								
Bases and acids:													
Silica (SiO_2)	......	10.33	2.52	......	......	1.34	.73	.05	......	3.03	.82	1.40	.96
Potash (K_2O)	......	......	......	6.76	1.76	5.14	.40	2.69	15.67	13.45	9.58	12.25	3.07
Soda (Na_2O)	44.44	43.86	48.97	27.60	38.39	36.99	39.64	42.07	41.57	41.64	45.59	43.03	51.29
Lime (CaO)	......	4.50	......	......	......	.15	......	.32	......	.05	.03	.11	......
Magnesia (MgO)	......	1.23	......	.35	......	.23	......	.51	......	.14	.07	.19	.06
Peroxide of iron (Fe_2O_3) and alumina (Al_2O_3)	......	......	......	......	......	.30	......	.41	......	......	.04	.07	......
Phosphoric acid (P_2O_5)	2.63	4.80	1.12	2.91	1.05	.09	.52	......	......	.63	1.05	.55	1.01
Sulphuric acid (SO_3)	2.19	5.52	24.78	6.43	13.20	51.23	19.82	37.88	9.47	1.65	.09	1.96	4.78
Nitric acid (N_2O_5)	6.81	......	......	......	10.50	......	......	......	......	......	......	......	......
Carbonic acid (CO_2)	26.19	17.92	13.20	16.69	11.62	.23	5.06	6.64	28.29	34.14	34.93	34.33	32.83
Chlorine (Cl)	.74	14.80	10.04	1.51	7.40	.29	19.20	6.57	6.39	.34	.99	.76	2.22
Ammonia (NH_3)	......	......	......	......	.42	......	......	......	......	......	......	......	......
Organic matter and water of crystallization	17.15	......	1.54	38.09	17.32	4.07	19.01	4.36	......	4.41	7.03	4.99	3.86
	100.15	102.96	102.17	100.34	101.66	100.06	104.38	101.50	101.39	99.48	100.22	99.64	100.08
Less excess O due to chlorine	.15	2.96	2.17	.34	1.66	.06	4.38	1.50	1.39	.07	.22	.17	.49
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.41	100.00	99.47	99.59

Composition of the soluble portion.

Compounds:													
Potassium sulphate (K_2SO_4)	......	......	......	20.23	3.95	10.13	.92	5.31	20.62	3.90	.16	4.53	6.27
Potassium carbonate (K_2CO_3)	......	......	......	......	......	......	......	......	6.59	18.44	15.17	15.90	......
Sodium sulphate (Na_2SO_4)	4.67	13.00	46.12	......	25.28	88.42	43.34	66.78	......	......	......	......	......
Sodium nitrate ($NaNO_3$)	12.98	......	......	......	19.78	......	......	......	......	......	......	......	......
Sodium carbonate (Na_2CO_3)	75.95	52.22	34.38	65.72	32.58	.42	15.38	15.85	62.22	75.61	80.36	77.10	87.14
Sodium chloride ($NaCl$)	1.46	33.00	17.45	3.98	14.75	.51	39.34	11.47	10.57	.52	1.76	1.34	4.03
Sodium phosphate (HNa_2PO_4)	4.94	1.78	2.05	8.42	2.25	......	1.02	......	......	1.53	2.55	1.13	2.56
Magnesium sulphate ($MgSO_4$)	......	......	......	1.65	......	.52	......	.59	......	......	......	......	......
Ammonium carbonate ($(NH_4)_2CO_3$)	......	......	......	......	1.41	......	......	......	......	......	......	......	......
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Composition of alkali in different states—Continued.

Ingredients.	Montana.					Nevada.	Wyoming.		Colorado.	Nebraska.†	
		Lewis and Clarke county.					Sweetwater Valley.				
	Meagher Co., Missouri Bottom, near Centerville Ferry Landing.	Prickly Pear Basin, near Helena.	Eight miles below Sun River crossing.	Choteau Co., Missouri River Bluff, opposite Fort Benton.	Meagher Co., Roberts Creek, Musselshell Valley.	Churchill county.*	Independence Rock Lake.	Saint Marys station, alkali.	Near Denver, alkali.*		
Bases and acids:											
Silica (SiO_2)	.05	.50	.02	.03	1.50	....	....	....	....	....	....
Potash (K_2O)	1.18	1.17	.87	4.12	1.53	....	....	....	....	....	....
Soda (Na_2O)	39.56	18.90	33.53	18.61	41.61	....	....	....	....	....	....
Lime (CaO)	2.86	1.91	1.81	.74	....	....	....	....	....	....	....
Magnesia (MgO)	1.31	11.19	4.49	12.79	....	....	....	....	....	....	....
Peroxide of iron (Fe_2O_3) and alumina (Al_2O_3)	....	.12	.08	....	....	....	....	....	....	....	....
Phosphoric acid (P_2O_5)	....	....	....	.06	....	....	....	....	....	....	....
Sulphuric acid (SO_3)	34.97	38.78	53.84	53.48	41.34	....	....	....	....	....	....
Nitric acid (N_2O_5)	5.37	....	....	....	....	....	....	....	....	....	....
Carbonic acid (CO_2)	1.19	2.56	.65	.26	5.38	....	....	....	....	....	....
Chlorine (Cl)	15.40	6.29	.50	.10	3.45	....	....	....	....	....	....
Organic matter and water of crystallization	1.29	19.72	4.39	9.50	5.78	....	....	....	....	....	....
	103.18	101.14	100.18	99.69	100.59	....	....	....	....	....	....
Less excess O due to chlorine	3.48	1.42	.11	.02	.80	....	....	....	....	....	....
Total	99.70	99.72	100.07	99.67	99.79	....	....	....	....	....	....

Composition of the soluble portion.

Compounds:											
Potassium sulphate (K_2SO_4)	2.37	3.07	1.77	8.59	3.07	....	....	....	....	....	....
Sodium sulphate (Na_2SO_4)	56.54	43.38	83.35	47.10	76.79	.55	73.17	88.93	93.40	10.80	15.30
Sodium nitrate ($NaNO_3$)	9.39	....	....	....	....	....	....	....	....	....	....
Sodium carbonate (Na_2CO_3)	....	....	....	.71	13.99	96.78	22.98	....	....	89.20	84.70
Sodium chloride ($NaCl$)	27.47	14.60	.91	.18	6.15	2.67	3.85	11.63	6.60‡	....	....
Magnesium sulphate ($MgSO_4$)	4.23	38.94	13.97	43.42	....	....	....	....	....	....	....
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Hayden's Report, 1871.
† Hayden, 1873.
‡ Common and Epsom salts.

It will be seen that all over the world the saline efflorescences, occurring over wide areas and owing their existence to general causes, have, as their prominent ingredients, the three sodium salts—chloride (common salt), sulphate (Glauber's salt), and carbonate (sal-soda). The relative proportions of these vary greatly, especially as regards the chloride and carbonate; the sulphate is on the whole the one almost invariably present in considerable proportion. In addition to these we find, usually in relatively small proportions, what might be called accessory ingredients, depending more or less upon local conditions, climatic as well as geological, but frequently of very great practical importance. Among these, the salts of potassium (potash), the nitrates, and the phosphates are of particular interest to agriculture, since they represent the three elements usually supplied in fertilizers; whence it follows that their presence in the soluble form in such proportions as to participate in the formation of alkali crusts on the surface is of no mean interest to the farmer, since it argues the occurrence of an excess of plant food in the soil, and, therefore, the needlessness of fertilization while this state of things continues.

It is, therefore, of special interest to determine to what extent the presence or absence of these accessories is dependent upon climatic conditions, and what local conditions may modify the result.

Nitrates.—Of the accessory ingredients, those most manifestly dependent upon climatic conditions are the nitrates. It is well known that the process upon which their formation depends is materially conditioned upon a certain high temperature (about 75° F.); a moderate degree of moisture, permitting the easy access of air and forbidding the existence of reductive fermentations; the presence of calcic or magnesic carbonate; and, most of all, upon that of the "nitrifying organism," without which the other conditions are powerless to act. Anything that paralyzes or destroys that organism is fatal to nitrification.

Among the ingredients that might be considered as certainly injurious to the life of the organisms in question are the chlorides of calcium and magnesium (bittern) and the carbonate of soda (and potash) when present in any large proportion, *e. g.*, so as to dissolve the humus of the soil, forming what is familiarly known as black alkali. We should therefore expect to find nitrates scarce or absent where large percentages of carbonate of soda are found in the alkaline salts and relatively abundant when sulphate and chloride are chiefly present. Actual examination fully confirms this *a priori* conclusion. The occurrence of nitrates in large proportion is confined to those regions in which white alkali is predominant—that is, neutral salts whose presence does not injure the activity of the nitrifying organism. This is confirmed also by the fact that the nitre beds of South America, as well as those of Nevada (White Plains), contain the saltpeter associated only with the two neutral salts—sulphate and chloride of sodium. The same rule will be observed to hold good in the cases in which nitrates are found in notable amounts in the alkali salts from Montana and California, of which analyses are given above. No nitrates are found in the highly carbonated salts of Washington.

We have thus in the necessarily calcareous nature of the soils of the arid region the fulfillment of one necessary condition of ready nitrification. In the moderate moisture condition of the soils of the same region a favoring condition, so far as oxidation is concerned, together with the substitution of eremacausis (slow combustion) of the soil humus in the place of the fermentations that under humid conditions frequently not only arrest all oxidation, but also, by the formation of poisonous compounds (ferrous and manganous salts), actually destroy the life of the nitrifying organism. Even the exceptional condition of a strong impregnation with carbonates of the alkalies does not act as unfavorably upon plant nutrition as might be inferred, for it is apparent from the analytical record as well as from the evidence of the senses that in that case the evolution of ammonia from the humus can serve as a source of direct supply to vegetation, and, finally, whatever nitrates are formed are not, as in humid climates, liable to be leached currently from the soil beyond the reach of plants, but remain year after year in actual accumulation. We are thus justified in the conclusion that aridity is peculiarly favorable to the supplying of nitrogen to plants.

Potash.—While the presence of this substance is to some extent dependent upon the character of the country rock, being often very high where (true) granites contribute largely to the soils, yet its accumulation in the soils themselves seems to follow, as a matter of course, along with and in preference to the sodium salts, the cause of the difference being its more tenacious retention by the soil. As regards the water-soluble salts, it is probable that where no potash appears in the analysis of an alkali salt it has simply been overlooked or neglected. It will be noted that in California and Montana potash salts frequently constitute from 7 to 10 per cent. of the whole mass of alkali, forming a supply that, when calculated to the soil mass to the depth to which the roots of crops are likely to reach, promises to defer indefinitely the need of supplying potash fertilizers to such soils. There does not appear to be any relation between the amounts of potash present and the neutral or carbonated condition of the salts.

Phosphoric acid or phosphates.—The slight solubility of earthy phosphates of necessity relegates the abundant occurrence of soluble phosphates to the cases where the salts are highly carbonated, it is therefore chiefly in the very black alkali that we find notable amounts of dissolved (sodic) phosphate. But in some cases these amounts are sufficient to promise the farmer, as in the case of potash salts and nitrates, a long exemption from the purchase of phosphate fertilizers.

In view of these facts, it seems abundantly worth while to examine carefully the conditions under which the two types of alkali salts—the neutral or white, and the alkaline, carbonated, or black—respectively occur, and to what extent we may be able to control their injurious effects upon vegetation.

FORMATION OF NATURAL DEPOSITS OF CARBONATE OF SODA.

It is curious to search in the past and even current literature on the general subject for a reasonable explanation of the occurrence of carbonate of soda in nature. There seems to be a consensus of opinion that the carbonation of the soda is connected in some way with the presence of limestone or the carbonate of lime, and that an exchange has occurred in which either common salt or Glauber's salt have transferred their acidic components to lime and have become carbonates instead. But how such an exchange is to be effected, in view of the exactly opposite reaction that occurs when alkali carbonates and earth sulphates or chlorides are brought in contact in our laboratories, has led to many wild conjectures without a tangible basis.

Yet the simple explanation of the contrary reaction was given and published as early as 1826 by Schweigger; in 1859 it was again observed by Alex. Müller, in a different form; but neither these chemists, nor any of their readers, appear to have perceived the important bearing of this reaction, not only upon the formation of the natural deposits of carbonate of soda, but also upon a multitude of processes in chemical geology.

Without going into detail, which has been published elsewhere,* it may be broadly stated that the formation of carbonated alkalies occurs whenever the neutral alkaline salts (chlorides or sulphates) are placed in presence of lime or magnesia carbonates *and* carbonic acid, or of alkali "super-carbonates" (hydro-carbonates) containing even a slight excess of carbonic acid above the normal carbonate; the latter being the actual condition of all natural sodas. In that case, crystals of gypsum may be seen, *e. g.*, in the residue from the evaporation of a mineral water which nevertheless shows a strong alkaline reaction; and such alkaline reaction is also obtained when carbonic acid is passed into a solution of common salt in which calcic carbonate is kept sussended, the formation of calcic chloride being simultaneous with that of the alkali hydro-carbonate.

It is easy to see that these conditions are constantly being fulfilled in nature; for the decay and fermentation of vegetable matter is constantly progressing in soils, swamps, and lakes, and as evaporation progresses the alkaline carbonate crystallizes out on the surface, or margins, while gypsum or calcium chloride accumulates on the bottom, or in the waters.

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*Proceedings of the American Association for the Promotion of Agricultural Science, for 1888 and 1890.

It has been shown above that the soils of arid regions are almost necessarily calcareous, free carbonate of lime being present; as are also the salts of the alkalies. The conditions for the formation of carbonates of the alkalies just recited are, therefore, fulfilled wherever enough of vegetable decay (or evolution of carbonic gas from other causes) goes on so as to impart even a slight excess of carbonic acid to the soil or other water; and thus black alkali is formed, to an extent depending upon the excess of carbonic acid available for the process. It is evident that this excess will be greater in moist, close soils, rich in humus, than in loose and pervious ones; and thus the fact that black alkali is mainly found in low ground, and in rather close soils, finds a ready explanation.

WARM CLIMATES FAVOR THE FORMATION OF SODA CARBONATES.

But since vegetable decay is essentially dependent upon a certain elevation of temperature, and is totolly suppressed by a certain degree of cold, it follows that, other things being equal, the formation of the alkaline carbonates will be most abundant in warm climates. The record of the occurrence of the soda deposits that in time past were of such industrial importance as the only sources of sodic carbonate, answers fully the requirements of this condition. Egypt, the African arid region generally, Mexico, the Aralo-Caspian lowlands, Turkestan, and the arid regions of western India, are the well-known sources from which the supplies of the mineral alkali (Trona, Urao) were formerly obtained. Were not the reaction limited to relatively dilute solutions,* its cheapness would soon drive all other processes of soda manufacture out of existence.

We do not, therefore, ordinarily expect to find alkaline carbonates abundant in the colder portions of the arid region; and this, as the table shows, is pointedly true as regards Montana. But in Washington, practically in the same latitude, the showing is quite different; we find here not only the carbonate of soda predominant, but it is present in percentages as high as those which, in Montana and California, are shown by the Glauber's salt.

But examination also shows, in the case of Washington, a special cause of this state of things. Almost the entire area on which alkali occurs in that state is covered by the black eruptive rocks, commonly, although to a great extent improperly, called basalts. As eruptives, these rocks are, of course, entirely free from gypsum, and but very rarely show even a trace of sulphurets. There is, therefore, no source from which sulphates could derive their essential ingredient; and thus the sodic carbonate, originally formed in the decomposition of the basalt by the atmospheric agencies, simply continues unchanged, as it emerges with the spring waters from the crevices of the rocks. Yet, in a few cases, where the basaltic eruptives are overlaid by a

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*The limit is reached at about .4 per cent.

somewhat considerable mass of stratified (cretaceous and tertiary) deposits, the sodic carbonate is in the minority, and, as in Montana, the sulphate predominates.

That such local accidents as these should bring about apparent contradictions is to be expected; yet, even in this case, they prove the rule.

RECLAMATION OF ALKALI LANDS.

While the details of the subject of reclaiming alkali lands, that is, freeing them from the injurious effects of the excess of salts so as to render them available for profitable culture, do not lie within the proper limits of this paper, yet the importance of the subject and its direct connection with climatic conditions render it desirable that it should be discussed at least in outline.

EFFECTS OF IRRIGATION UPON ALKALI SOILS.

Since, as has been elaborately discussed above, the occurrence of soluble salts in soils is directly due to deficient rainfall and consequent failure to leach out the soluble matters, the direct inference might be that when irrigation makes up this deficiency to the extent required by success in cultivation, the normal leaching process would be established, and trouble from that source would cease. So far from this, it is found in practice that irrigation greatly increases the accumulation of alkali at or near the surface, often to such an extent as (in the case of black alkali) to render cultivation impossible or at least unprofitable.

The reason of this apparent discrepancy is simply that the amount as well as the distribution of the irrigation water is different from that of the rainfall of the humid regions. Usually the amount of irrigation water used is less than the annual rainfall of humid climates; and besides, it is used in great abundance for a short time, the object being to wet the soil just to the necessary depth and no more. The water thus used carries the alkali with it; but as it does not reach the country drainage, when evaporation begins it re-ascends and, finally, if the whole of the water evaporates, the whole of the alkali comes to, or close to, the surface. Now as irrigation in the arid regions usually penetrates deeper than the rains, this implies that a larger amount of alkali is now carried to the surface than was the case before. If, worse than this, a pervious soil and leaky irrigation ditches gradually fill up the whole country with water from below, the entire amount of alkali salts previously existing in the dry soil mass, perhaps to depths of forty or fifty feet, is brought near the surface, and thus the bottom water becomes the source of an almost inexhaustible supply of alkali, which may render the further cultivation of the lands impossible unless done away with.

UNDERDRAINAGE THE UNIVERSAL REMEDY.

It is obvious that all these difficulties could be remedied by underdrainage; for it would be perfectly easy to wash out of the soils above such drains every trace of alkali by one somewhat prolonged flooding; and as the bottom water would likewise be held in check by the same drains, no further supply would rise from below even in case of an ascent of the irrigation water by "filling up." Underdrainage is, therefore, a complete and full remedy for alkali lands.

But underdrainage is expensive; moreover, as we have seen, the alkali salts themselves are far from being throughout injurious, but do in fact almost always contain highly valuable soil ingredients in the most available form. To leach these out means a heavy loss of plant food, which would sooner or later have to be made up by the purchase of fertilizers.

REMEDIES OTHER THAN UNDERDRAINAGE.

If, then, there are other less radical remedies that can be applied by the farmer, their use is to be preferred on that ground alone. These possible remedies will be briefly stated:

1. Since the soil water is very rarely so strongly tainted with alkali salts as to injure the roots directly, but becomes harmful mainly when accumulated at or near the surface to such an extent as to corrode the root crown, the obvious remedy consists in preventing such accumulation by checking evaporation. Deep and thorough tillage persistently maintained throughout the season is alone, in a large number of cases, all that is necessary for perfectly successful cultivation of light alkali lands; provided always that the alkali be in the main white, that is, consists of the sulphate and chloride of sodium, and does not contain any large proportion of carbonate of soda.

Occupation of the land by a crop that fully shades the soil and rerestricts evaporation to that which goes on through the leaves of the plants, also permits of profitable use of alkali soils. Such crops are, for instance, alfalfa, ramie, clovers, etc. The main difficulty is usually to secure a stand of such crops, because of the injurious effects of the salts on germination. The same difficulty is experienced in rooting cuttings, but the planting of rooted stock usually succeeds with good tillage.

2. If, however, the alkali be of the black kind, strong enough to dissolve wholly or partially the humus of the soil, the first thing needful is the neutralization of the carbonate, which, when raised to the surface, not only exerts a powerfully corrosive action upon the root crowns and stems of plants, but kills all small seeds and thus prevents the obtaining of a stand. But its injurious action does not end there; in even moderately clayey soils it renders tillage almost impossible by destroying the tilth or "flocculation" of the clay, and converting the soil into a mass more suitable for the potter's lathe than for tillage. Moreover, it dissolves that important soil constituent, humus or vegetable mold, and, as has been stated already, by impairing or destroy-

ing the vitality of the nitrifying organism it also prevents one of the most essential processes in the soil, conducive to plant nutrition.

GYPSUM NEUTRALIZES BLACK ALKALI.

The neutralization or transformation required is easily and cheaply accomplished by the use of gypsum or land plaster, which, under normal conditions of culture, exchanges its acidic constituent with the sodic carbonate, resulting in the formation of carbonate of lime and sulphate of soda, or Glauber's salt, in other words, white alkali.

The contrary reaction, by which limestone and Glauber's salt may form carbonate of soda and gypsum, can only occur under conditions incompatible with good cultivation, and practically, as experience shows, does not occur to a sufficient extent to vitiate the practical success of the gypsum treatment of black alkali lands.

3. But the usefulness of the gypsum does not end there. While correcting the physical (tillage) conditions of the soil and preventing any damage by corrosion, it also renders insoluble the humus taken up and dissolved by the carbonate of soda, giving it back to the soil. Moreover, when soluble phosphates are present, this precious soil ingredient is also withdrawn from solution and is retained in the soil in a most effective form.

Whether or not gypsum also tends to render potash held in solution less soluble by the formation of complex silicates is a point not yet determined. It of course does not and cannot prevent the waste by leaching out of the important and costly nitrates through any chemical action. But as, practically, the use of gypsum in sufficient amounts renders unnecessary, probably in three out of four cases, the resort to the costly ultimate remedy, underdrainage, and enables the farmer to deal with the alkali by merely maintaining very thorough cultivation, it does to that extent subserve an important use in respect to the saving of nitrates also.

So far, then, as the dreaded alkali salts are concerned, it is perfectly feasible, in the vast majority of cases, to conquer them by the judicious use of these remedies, retaining in the soil a wealth of plant food which in humid climates would have passed into the streams and the sea.

4. *Calcareous hardpan.*—As to the frequent occurrence of calcareous hardpan—the kankar of the "usar-lands" of India—it adds a difficulty in preventing the penetration of roots as well as of water; and when leaky irrigation ditches in pervious soils cause the bottom water to rise from below, the saline solution that forms the upper layer of that water (as the result of upward leaching of the whole soil) flows in over the edges of the basin-shaped hardpan areas, and of course remains and evaporates there, causing a local and exceedingly rapid increase of the alkaline impregnation, sometimes resulting in the formation of small alkali ponds.

The breaking-up of this hardpan layer is the most important thing to be done; but as it rarely lies shallow enough to be reached even by the deepest plowing, it has been found best to reserve such lands for the planting of fruit trees, or vines, and before doing so to break up the hardpan around the spots, where the holes are made either with crowbars or (in America at least more cheaply) by small charges of moderately strong dynamite, which so shatter and crack the hardpan that not only can can roots penetrate to a sufficient extent, but the drainage thus induced seems often to gradually so soften and crumble the mass that it practically disappears as an obstacle to cultivation.

In cases where the existence of hardpan had not been observed until the trees planted began to languish on account of the inability of their roots to penetrate to sufficient depth, the use of dynamite cartridges on opposite sides of the young trees has produced the necessary relief without injury to the trees.

Clayey hardpan.—On the other hand, the compacted, puddled, clayey layers that sometimes takes the place of the calcareous hardpan in bad cases of black or carbonate alkali, and are equally injurious, yield gradually to the effects of the neutralization of the carbonates by gypsum, which destroys the puddled condition of the clay brought about by the carbonated alkali and thus enables roots to penetrate, and water to drain through these layers. This effect of gypsum may be seen strikingly on pieces of such clayey crust that have been brought to the surface and treated with gypsum, which within a few days causes them to crumble, and assume the normal condition of soil.

CONCLUDING REMARKS.

In the summary review of the relation of climate to soils—the two factors which essentially control the production of the necessaries of life—that forms the subject of this paper, the scantiness and incompleteness of the data thus far available on a topic as interesting theoretically, as practically important, is painfully apparent; and to no one more so than to the writer himself, who has made soil studies a favorite pursuit during most of his active life. While the intrinsic difficulties to be met in such an investigation are sufficiently great, the remarkable looseness of observations bearing upon it, their usually sporadic and unsystematic nature, and the fact that they are so thinly scattered in various kinds of literature—travels, geography, statistics, reports on geological, meteorological, topographical, and even botanical topics, together with enclycopedias and miscellaneous technical works of reference, renders their collation and elaboration very laborious and thus far rather unsatisfactory. It should not, therefore, be surprising to anyone if in this first attempt at a systematic exposition of the subject there are many important gaps and omissions that might have been avoided had a more complete library and a larger share of leisure been at command.

It may be hoped, however, that this paper may serve at least the purpose of enlisting in the study of this, the latest phase of chemical geology, a larger number of active workers and observers, so that at least the large amount of information actually existing may be gathered together and made practically useful; thus leading the way to a better understanding of the character, capabilities, and needs of the lands of the various regions, and of the means of utilizing them to the best advantage. The eminently practical nature of such investigations should commend them to greater attention from public geological surveys, in which a vast amount of labor is devoted to subjects of very much less interest and importance, whether theoretical or practical. The apathy that has prevailed, in regard to these studies, would be difficult to understand but for two considerations, one historical, the other intrinsic. From the latter point of view, the undeniable difficulty and complexity of the subject of soil study, and the want of immediately brilliant and remunerative results to the worker, is no mean detterent factor. Historically, direct soil investigation received a set-back in the early part of this century, when upon extravagant expectations from its application to agriculture there followed a reaction which has not even yet subsided entirely. But it certainly is high time that such prejudices should give way to a reasonable reconsideration of the facts from a modern scientific standpoint; and that in the prosecution of public surveys, the interests of agriculture should cease to be the stepchild of which the name is used only for the sake of conciliating the favor of the large class dependent upon its intelligent prosecution. Conjointly with the study of soils, that of climatic conditions is of the utmost practical and theoretical importance; and ample means for the prosecution of both branches of study should be provided. The Experiment Stations of the United States, as now constituted, have not the means for a sufficiently rapid and energetic prosecution of either, to respond to the demands made upon them. Meteorological stations must be made more numerous, and should largely be located with reference to the agricultural problems to be determined in connection with them. Actual field surveys to define the agricultural subdivisions and to study their peculiarities should be made by parties covering ably not only the agricultural, but also the meteorological, geological, and botanical aspects of the several problems. This will be but simple and tardy justice to the fundamental industry upon which the very existence of nations depends.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 4.

SOME PHYSICAL PROPERTIES OF SOILS

IN THEIR RELATION TO

MOISTURE AND CROP DISTRIBUTION.

BY

MILTON WHITNEY,
Professor of Geology and Soil Physics, Maryland Agricultural College;
Physicist, Maryland Agricultural Experiment Station;
Fellow by Courtesy, Johns Hopkins University.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., July 28, 1892.

SIR: I have the honor to transmit herewith a paper entitled "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution," prepared by Prof. Milton Whitney, of Johns Hopkins University, and to recommend its publication as Weather Bureau Bulletin No. 4. In this connection I would state that this is the second paper of a series on the relations of soils to meteorology, the object of which is to elicit information from specialists, rather than to indicate the views held by the Department on the subjects treated.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

Hon. J. M. RUSK,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., July 1, 1892.

SIR: I have the honor to submit herewith my report entitled "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution."

The work for the Department has covered a period of only six and a half months and on the soils of Maryland of only a few months longer. Much of this time has necessarily been spent in collecting material and in other preliminary work. The work is to be continued and the physical properties and conditions of these soils will be studied in still more detail.

This report is based partly on my own original work and partly on a generalization of the work of others in this line, as reported in the literature of the day. The limits of this report would not allow of the presentation of even the main facts from which these generalizations have been drawn, which are well known, however, through the admirable writings of Johnson and Storer, or of the views generally held by agricultural chemists as to the cause of the local distribution of plants. It is believed, however, that although these views and generalizations may appear at first sight to differ from the present theory of fertilization, a more careful consideration will show that they supplement rather than conflict with the views commonly held by agricultural chemists.

Very respectfully,

MILTON WHITNEY.

MARK W. HARRINGTON,
Chief of Weather Bureau.

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SOME PHYSICAL PROPERTIES OF SOILS IN THEIR RELATION TO MOISTURE AND CROP DISTRIBUTION.

INTRODUCTION.

The history of soil investigations forms a very interesting chapter in scientific literature. It has not been many years since it was generally believed that the chemical analysis of a soil would show what class of plants the soil is best adapted to produce, and what elements of plant food are lacking in the soil for the best development of other crops. It was found, by a vast amount of work on the chemical composition of soils and plants, that all soils contain a large amount of plant food, while the relatively small amount removed by crops in a series of years can not be detected by chemical means, although, as the result of injudicious methods of culture during this period, the soil may deteriorate and the yield of crop fall below the limit of profitable cultivation. It was then believed, and it is still held, that only a small proportion of the plant food in the soil is in such a form as to be readily available to plants, and that this may readily revert to an insoluble or unavailable form if it is not quickly used up by plants.

Various solvents have been suggested and tried to determine the amount of available plant food in the soil. Plot experiments with manures and fertilizers have been carried out to ask of the soil the direct question, what amount of available plant food is needed in order to insure a maximum crop.

Some rather anomalous facts have been shown in this work. A plant having a large amount of nitrogen, for example, in its composition, will not necessarily respond to a manuring with this particular ingredient, but will respond readily to a manuring of another substance, of which it uses only a relatively small amount, while other plants, containing a small amount of nitrogen in their composition, will respond readily when manured with this substance, even on the same land. This is supposed to be due to a difference in the feeding capacity of the plants. A plant which responds readily to a nitrogenous manuring one year may respond more readily to a phosphatic manuring on the same soil the next year if the *season* is different. The standard fertilizing materials frequently give a lower yield of crop than is produced where nothing has been added to the soil; and, on the other hand, a very small addition of a fertilizer may increase the crop to an extent out of all proportion to the amount of plant food added to the soil. This is especially true of stable manure and lime.

There has been no satisfactory interpretation, as yet, of much of the work which has been done on the chemical composition of soils and plants, and the results of plot experiments have, in most cases, been very conflicting and uncertain.

The physical conditions of growth have been recognized as of importance, and of controlling importance in many cases, but their influence has hardly been considered in soil investigations. Records have been carefully kept of all the ordinary meteorological conditions and atmospheric changes, but there has been, in most cases, no interpretation of the results; and the results have been given and remain as a mass of unintelligible and seemingly useless figures.

The distribution of our staple crops, according to the meteorological conditions which prevail in the country, has been very ably discussed by Brewer in the tenth census. It is undoubtedly due to these meteorological conditions, rather than to any difference in plant food or in methods of cultivation, that the average yield of grain per acre in the Southern States is only about one-third of that in the North and West. The conditions at the South are more favorable to long continued growth of leafy matter, and it is difficult to check the growth of the plant and make it produce a fair yield of grain. It is only since the introduction of commercial fertilizers, which have hastened the ripening of the crop, that cotton has been successfully grown as far north as the upper counties of North Carolina, and it is only by improved methods of cultivation that the Sea Island cotton has been made to mature within the season which prevails in South Carolina. Temperature, of course, is a very important factor in plant development, and this alone determines the general distribution of many plants, and prevents tropical fruits being produced in the short season of the Northern States. It is not that the soils of Pennsylvania are less rich in plant food than the soils of Florida, or that the plant food is in a different form of combination, but that temperature is the controlling cause in crop production. This is such an every-day matter that it is hardly realized that temperature is such a potent factor in the distribution of crops, and that even our own seasonal changes must have a more important effect on the development of plants than is usually considered. But even over small areas, where the meteorological conditions cannot be very different, the texture of the soils may be so different that they maintain very different conditions of heat and moisture for the growing crops. In these local conditions, moisture seems to be far more important than heat, and the relation of the soil to moisture largely determines the relation of the soil to heat. However potent, therefore, the factor of temperature may be in the general distribution of crops, the relation of soils to moisture, or the amount of moisture they may maintain under existing meteorological conditions, is quite as important a factor in the local distribution and development of plants. The texture of the soil and its condition and treatment have been recognized as of importance in determining crop distribution and development, but there has been no interpretation or expression of these physical conditions of the soil which could be used in the calculation of results of the soil investigations. It is proposed in this paper to show that the physical properties of soils very largely determines the local distribution and development of plants, and to suggest methods for the study and expression of the physical properties and condition of the soil.

A preliminary report of these soil investigations was published in the Fourth Annual Report of the Maryland Agricultural Experiment Station, and this will be freely used in the present paper, as well as some unpublished matter on investigations of a similar character, carried on by the writer at the South Carolina Experiment Station.

In the older agricultural regions of the country in the Eastern and Southern States, especially below the influence of the glacial action, there are many large areas of well marked and very uniform soil conditions, corresponding to different geological formations, where the distribution and production of crops seem to be dependent upon the texture of the soil. There is a certain type of land in certain geological formations which is so coarse and open in texture that it is permitted to remain in pine barrens; there is another type bordering the coast, in a different geological formation, which is well suited to melons and early vegetables; still other types of soil are suited to different grades of tobacco and to wheat and grass.

The agricultural chemist has approached this subject through the study of the chemical composition of soils and plants, and has attempted to explain the distribution of plants through the minute differences in chemical composition or in the form of chemical combination of the ingredients in the soil. The practical farmer, on the other hand, can judge much more correctly of the condition of the land and what it is best fitted to produce, from the general appearance or physical texture and structure of the soil. It is a matter of common experience to him to judge from the texture and general appearance of the soil what crop it is best fitted to produce, and what general treatment should be pursued in the production of the desired crop. He knows that wheat can not be economically produced on light sandy lands, under prevailing climatic conditions, and that no addition of mere plant food will cause a good wheat crop to be produced on such a soil without resorting to irrigation, where the water supply can be controlled, or without first changing the texture of the soil so as to make it more compact and more retentive of moisture, so that it can maintain a more abundant supply of water for the crop. It is a matter of the available water supply maintained by the soil rather than of the available plant food which determines this local distribution of plants. Under the same climatic conditions the wheat land will maintain two or three times as much moisture for the use of the crop as the light sandy lands. If the conditions in the wheat land are normal, and are necessary conditions for the wheat crop, which can not be doubted in view of the number of determinations which have been made, then there is something radically wrong in the light truck land as a wheat soil, and this relation of the soil to moisture becomes as potent a factor as a controlling cause as temperature is in the economical production of oranges, bananas, and pineapples in the Northern States.

It may be objected that not enough importance is given to the chemical side in this treatment of the subject, but if the relation of the soil to moisture is conceded to be a controlling cause in the local distribution of wheat on these two types of soil, as would be claimed in this case by any practical farmer, then this alone is to be considered first, and all changes, treatment, and improvement of the land must be along this line. A farmer is a man of rare experience and observation in these lines, and is to be relied on in matters of fact, however much those of us who are engaged in purely scientific work may disagree with him in deductions from these facts. The facts themselves must be accepted and be the basis for scientific work. How common it is in the improvement of lands to hear of a refractory clay being made more loamy by judicious treatment, and a loose, incoherent sand being made more retentive of moisture.

Now it seems that there must be some explanation, some interpretation, and some expression of this fact that the farmer can judge of the agricultural value of a land and the kind of crop which it can or can not produce, from the general appearance of the land, that is, from the physical texture and structure of the soil. It would seem that this must come through the proper interpretation of the mechanical analyses of soils. The results of the mechanical analyses, as usually given, have little meaning, for there is little or no attempt at the interpretation of the results, and there is no expression of the results which can be used in forming a definite opinion of the character of the land.

It is proposed to suggest here an interpretation of the mechanical analyses of soils which shall explain and define these visible signs upon which the practical farmer bases his judgment of the agricultural value and condition of the soil, and which can be used, in relative terms at least, in the expression of results of soil and plant investigations.

It will be necessary first to discuss some of the fundamental principles upon which this interpretation is based and then to present problems with an application of the principles. The primary conceptions upon which this is based may be briefly stated as follows: The circulation of water in the soil is due to gravity, or the weight of water, acting with a constant force to pull the water downward, and *also* to surface tension or the contracting power of the free surface of water (water-air surface), which tends to move the water either up or down or in any direction, according to circumstances. The ordinary manures and fertilizers change this surface tension, or pulling power, of water.

There is a large amount of space between the grains in all soils, in which water may be held. The rate of movement of the water will depend upon how much space there is in the soil; upon how much this space is divided up, *i. e.*, upon how many grains there are per unit volume of soil; upon the arrangement of the grains of sand and clay; and upon how this skeleton structure is filled in and modified with organic matter.

The arrangement of the grains, and consequently the texture or structure of the soil, may be changed through the effect of the ordinary manures and fertilizing materials, causing flocculation or the reverse.

THE CIRCULATION OF WATER IN THE SOIL.*

The motive power which causes water to move from place to place within the soil consists of two forces: gravity, or the weight of the water itself, and surface tension. Gravity tends to pull the water downward, and acts with a constant force per unit mass of water, neglecting the slight difference due to elevation and to latitude. Surface tension, or the contracting power of any exposed water surface, may move the water in any direction within the soil, according to circumstances. It may act, therefore, with gravity to pull the water down, or against gravity to pull it up. The force of gravity need not be further considered here.

Surface tension is the tendency which any exposed surface has to contract to the smallest possible area consistent with the weight of the substance. If a mass of water is divided, or cleft in two, leaving two surfaces exposed to the air, the particles of water on either surface, which were before in the interior of the mass and attracted from all sides by like particles of water, have now water particles on only one side to attract them, with only a few air particles, comparatively very far apart, on the other side, where formerly was a compact mass of water. All the surface particles of water will therefore be pulled from within the mass of water, and the surface will tend to contract as much as possible, leaving exposed the smallest number of

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*Much of the discussion of these underlying principles is taken from a preliminary paper in the Fourth Annual Report of the Maryland Agricultural Experiment Station.

surface particles, and causing a continual strain or surface tension. On any exposed water surface there is always this strain or tension ready to contract the surface when it may.

It is a constant, definite force per foot of surface for any substance at a given temperature. In the case of liquids and solutions, in which we are most interested, it varies with the nature of the liquid and the substance in solution.

This is surface tension; and we have it in the soil as a strain or tension along the free surface of water within the soil, which tends to contract the surface and so move the water from one place to another as it is needed.

There is, on an average, about 50 per cent. by volume of space within the soil which contains no solid matter, but only air and water. This we shall call empty space. In a cubic foot of water there is about half a cubic foot of empty space, but this is so divided up by the very large number of soil grains that the spaces between the grains are extremely small.

When a soil is only slightly moist the water clings to the soil grains in a thin film. It is like a soap bubble with a grain of sand or clay inside, instead of being filled with air. Where the grains come together the films are united into a continuous film of water throughout the soil, having one surface against the soil grains and the other exposed to the air in the soil. As the soil grains are surrounded by this elastic film, the tension on the exposed surface of the water will support a considerable weight, for the soil grains, thus enveloped, are extremely small and have many points of contact around which the angle of the surface is more acute and the film is thicker and is held with greater force.

If more water enters the soil the film thickens, and there is less exposed water surface. If the empty space is completely filled with water there will be none of this exposed water surface, and, therefore, no surface tension. Gravity alone will act and with its greatest force. If the soil is nearly dry there will be a great deal of this exposed water surface, a great amount of surface tension, and, with so little water present, gravity will have its least effect.

The grains in a cubic foot of soil have, on an average, no less than 50,000 square feet of surface area. There is less, of course, in a sandy soil, and more than this in a clay soil. If there is only a very small amount of water in the soil the film of water around the grains will be very thin, and there will be nearly as much exposed water surface as the surface area of the grains themselves. If a cubic foot of soil, thus slightly moistened, and having this large extent of exposed water surface, be brought in contact with a body of similar soil fully saturated with water, in which there is none of this water surface, the water surface in the drier soil will contract, the film of water around the grains will thicken, and water will be drawn from the wet into the dry soil, whether it be to move it up or down, until, neglecting gravity or the weight of water itself, there is the same amount of water in the one cubic foot of soil as in the other. When equilibrium is established there will be the same extent of exposed water surface in these two bodies of soils.

When water is removed from a soil by evaporation, or by plants, the area of this exposed water surface is increased, and the tension tends to contract the surface and pull more water to the spot.

When rain falls on rather a dry soil the area of the exposed water surface in the soil is diminished, and the greater extent of water surface below contracts and acts, with gravity, to pull the water down.

Fertilizers change this surface tension and modify the contracting power of the free surface of water to a remarkable degree, and so modify the power which moves water from place to place in the soil.

The following table gives the surface tension of a solution in water of several of the ordinary fertilizing materials. The surface tension is expressed in gram-meters per square meter, that is, on a square meter of liquid surface there is sufficient energy to raise so many grams to the height of one meter.

Where the substance was sufficiently soluble the solution was made up to a specific gravity of 1.1000, but where the substance was not sufficiently soluble for this, 10 grams were digested for twenty-four hours with 100 cubic centimeters of distilled water. All the solutions were filtered through washed filters before being used. The ordinary city supply, from a faucet in the laboratory, was used for the determinations made last year, contained in the first part of the table; and such water is usually considered the best for such work, as the water is drawn out of a large body from below the surface. For the later results, however, ordinary distilled water had to be used, but all the water used was taken from the same supply and was siphoned off when needed:

Surface tension of various solutions.

(Gram-meters per square meter.)

Solution of—	Specific gravity.	Number of measurements from which the mean is taken.	Mean.	Highest.	Lowest.
Salt	1.070	6	7.975	8.126	7.796
Kainit	1.053	6	7.900	7.993	7.805
Lime	1.002	4	7.696	7.750	7.674
Water	1.000	18	7.668	7.923	7.506
Acid phosphate	1.005	4	7.656	7.800	7.563
Plaster	1.000	9	7.638	7.730	7.572
Ammonia	0.960	6	6.869	6.950	6.826
Urine	1.026	10	6.615	6.740	6.471

Surface tension of various solutions.

(Gram-meters per square meter.)

Solution of—	Specific gravity.	Surface tension.	Solution of—	Specific gravity.	Surface tension.
Magnesium chloride	1.1000	7·964	Wood ashes	1.0038	7·674
Common salt	1.1000	7·911	Potassium nitrate	1.1000	7·661
Muriate potash	1.1000	7·907	Potassium sulphate	1.0830	7·658
Thomas slag	1.0012	7·890	Ammonium nitrate	1.1000	7·656
Kainit	1.1000	7·889	Dried fish	1.0026	7·594
Marl	1.0013	7·855	**Water**	**1.0000**	**7.532**
Potassium chloride	1.1000	7·853	Stable manure	1.0013	7·464
Ammonium sulphate	1.1000	7·834	Acid phosphate	1.0104	7·414
Dried blood	1.0001	7·764	Cotton-seed meal	1.0054	6.534
Ground bone	1.0007	7·749	Tankage	1.0169	4·844
Sodium nitrate	1.1000	7·730	Cotton seed	1.0070	4·788
Sodium sulphate	1.1000	7·730			

Surface tension of soil extracts.

No.	Soil.	Specific gravity.	Surface tension.
295	Kentucky blue grass	1.000	7·244
281	Triassic red sandstone	1.000	7·244
279	Wheat	1.000	7·098
....	Garden	1.000	7·089

The determination was made by the method of the rise in a capillary tube. A short piece of thermometer tubing was used, the diameter of the bore being determined by careful microscopic measurements with a micrometer eye piece. Sections of the tube, above and below the piece taken, appeared very uniform and so nearly circular as to be within the limit of error of observation. The diameter of the tube was taken at 0.5578 millimeters, and the figure 0.0558 centimeters was used in the calculation of the results. The tube was very thoroughly cleaned after each observation, or set of observations, with a strong caustic potash solution, and, after washing, was allowed to stand for some time in a saturated solution of bicromate of potash in strong sulphuric acid. The height of the rise in the capillary tube was measured with a cathetometer.

The following formula was used for the calculation of the results:

$$T = \frac{h\ d\ \omega}{4\ cos.\ a}$$

Where T is the surface tension; *d* is the diameter of the tube in centimeters; *h* the height to which the liquid rises in the capillary tube in centimeters; ω is the specific gravity of the solution; and 4 *cos. a* refers to the angle of the liquid with the side of the glass tube. In regard to this latter, 5° 24′ was taken as the edge angle. This is the mean of 11 determinations given by Quincke of the edge angle of pure water and glass.* In regard to saline solutions, Quincke says, that "according to these researches the edge angle

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*Quincke on edge angle and spread of liquid on solid bodies, Phil. Mag., 1878.

appears to increase a little with augmenting concentration of the saline solution, but otherwise, to differ only inconsiderably from the edge angle of pure water."

In regard to the results themselves, most of the salts have increased the surface tension of the water, while the organic matters have generally lowered it. Cotton-seed meal, tankage, and cotton seed have lowered the surface tension very considerably. The determinations of the surface tension of these three substances were not very satisfactory, as the solutions were very viscous and moved very slowly in the capillary tube, continuing to fall for a long time after the tube had been immersed and raised again in position for the reading. The very low result with the cotton seed is probably due to the oil, most of which is expressed in the preparation of the meal.

Cotton seed and cotton-seed meal are both used as fertilizers in large quantities at the South. Opinion seems to be very evenly divided as to which gives the better results; some claiming good results from the one and rather injurious results from the other. It has been argued that as the oil has no fertilizing value its presence can do no good in a fertilizer, but on the contrary may do harm, by preserving the substance from disintegration and solution; and it has been argued that it is not only a profit to the cotton planter to have his seed converted into meal, from the value of the oil obtained, but that the value of the product itself is increased as a fertilizer. There are so many positive statements, however, of the greater value of the seed on certain soils than of cotton-seed meal, that I cannot but think in some soils or under some conditions the oil in the seed must have a beneficial effect, apart from any slight fertilizing value it may have, in its effect on the physical condition of the soil due to this very low surface tension of its extract, and in the effect which it may have on the arrangement of the soil grains through flocculation or the reverse.

It has frequently been observed that an application of magnesium chloride, salt, or muriate of potash tends to keep the soil more moist in dry weather. These substances have the highest surface tension of any in the table. They would tend to increase the surface tension of the soil moisture and increase the power the soil has of drawing water up from below, and it is probably this which explains the action of these salts referred to.

On the other hand, the injudicious use of concentrated organic matters in a dry season may "burn out" the land and make it drier than it would otherwise be, as the organic matter would lower the surface tension of the soil moisture and the soil would have less power of drawing water up from below for the support of crops; although their judicious use in favorable seasons would tend, in another way, to make the soil more retentive of moisture, as will be shown.

The surface tension of several soil extracts are given in the table, and these are seen to be very much lower than that of pure water. The extracts were made by rubbing up 10 grams of the subsoil with just sufficient water to cover it, and this was allowed to digest for twenty-four hours, being frequently stirred. The extracts were, in most cases, turbid, but the matter in suspension was so fine that it could not be removed with a filter.

The contact of the water with the subsoil lowered the surface tension very considerably, but as this extract was still very much more dilute than the ordinary soil moisture the surface tension of the soil moisture itself must be assumed to be considerably lower than the tension of these extracts. It was not considered advisable at this time to extend these investigations further, although there is an opening here for some interesting work.

There is a very interesting application of this low surface tension of soil moisture. It is a matter of very common experience with gardeners that if a plant or piece of lawn is watered in a very dry season, by applying water to the surface of the ground, the watering has to be continued thereafter during all the dry season, as the result of a single watering is to leave the ground drier than it would otherwise have been. They usually put off watering as long as possible for this reason, and when they once begin they continue it. King has proved this experimentally by watering a piece of ground and letting it stand for twenty-four hours. He then found by direct determinations that the upper foot was wetter than immediately before the watering, but that the lower depths of the soil, down to 36 inches deep, were drier than before the watering. It would seem in this case that the higher surface tension of the pure water, or of the more dilute soil moisture in the surface soil, had pulled up water from below, where the surface tension is less, and the danger would be that this water being brought near the surface would then evaporate quickly, and so more of the original soil moisture would be lost by evaporation than if the water had not been applied to the surface.

Several years ago the writer called attention to the interesting fact that the level of the water in the wells in the grounds of the Agricultural Society in Raleigh, N. C., was lowest during the winter months and gradually rose, notwithstanding the spring and summer droughts, reaching its maximum about August. Goff published similar observations on a well at the New York Experiment Station. In the Sand Hill formation at Columbia, S. C., the wells are at their fullest during excessive dry weather, but immediately begin to fall after a soaking rain following a long dry spell. The application of the foregoing principles seems apparent here, that as the soil becomes drier the surface tension of the soil moisture is reduced so that it can not maintain the water at the same height as formerly. The water from the lower depths of the subsoil is, therefore, let down into the well as the surface soil becomes drier and the surface tension of the moisture in the upper layers of the soil is diminished through concentration of the solution. With a soaking rain, the pure water increases the surface tension of the moisture in the upper layers of the soil, and while there is less extent of surface to contract, the greater contracting power more than counterbalances this and water is drawn up from below, or, at least, does not flow so readily into the well.

To sum up, it may be briefly stated that the surface tension, or lifting power of soil moisture, is much lower than that of pure water. Many of the common fertilizing materials increase this surface tension of the soil moisture and increase the power the soil has of drawing water up from below in a dry season, or of drawing water to a a plant to replace that which has been lost by evaporation or has been used up or transpired by the plant. On the other hand, many organic substances lower the surface tension, or pulling power, of water very considerably and lessen the power the soil has of pulling water up from below to supply the loss due to evaporation, or what has been used by plants.

This effect of fertilizing materials in changing the surface tension of a liquid, and thereby changing the force or power which moves water from place to place in the soil, is only a first effect, as the continued use of these fertilizing materials may change the texture of the soil itself and the relation of the soil to the circulation of water.

THE EFFECT OF FERTILIZERS ON THE TEXTURE OF THE SOIL.

Surface tension may be expressed in another way.* The potential of a single water particle is the work which would be required to pull it away from the surrounding water particles and remove it beyond their sphere of attraction. For simplicity, it may be described as the total force of attraction between a single particle and all other particles which surround it. With this definition it will be seen that the potential of a particle on an exposed surface of water is only one-half of the potential in the interior of the mass, as half of the particles which formerly surrounded and attracted it were removed when the other exposed surface of water was separated from it. A particle on an exposed surface of water, being under a low potential, will therefore tend to move toward the center of the mass where the potential, *i. e.*, the total attraction, is greater, and the surface will tend to contract so as to leave the fewest possible number of particles on the surface.

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*This treatment of the subject was suggested by an article by Lord Rayleigh in the Phil. Mag., Nov. and Dec., 1890; and I am further indebted to Dr. Arthur L. Kimball, formerly of the Johns Hopkins University, but now of Amherst, Mass., for much valuable advice and suggestion in the application of the principles to the phenomenon of flocculation.

If instead of air there is a solid substance in contact with the water, the potential will be greater than on an exposed surface of the liquid, for the much greater number of solid particles will have a greater attraction for the water particles than the air particles had. They may have so great an attraction that the water particle on this surface, separating the solid and liquid, may be under greater potential than prevails in the interior of the liquid mass. Then the surface will tend to expand as much as possible, for the particles in the interior of the mass of liquid will try to get out on to the surface. This is the reverse of surface tension. It is surface pressure, which may exist on a surface separating a solid and liquid.

This probably explains the phenomenon of flocculation, a phenomenon of very great importance in agriculture.

Muddy water may remain turbid for an indefinite time. If a trace of lime or salt be added to the water the grains of clay *flocculate*, that is, they come together in loose, light flocks, like curdled milk, and settle quickly to the bottom, leaving the liquid above them clear. Ammonia and some other substances tend to prevent this and to keep the grains apart, or to push them apart if flocculation has already taken place. This is similar to the precipitation of some solid matters from solution. When lime is added to a filtered solution of an extract of stable manure, the organic matter is precipitated in similar loose, bulky masses. This matter of potential would seem to have a bearing on all cases of precipitation, as the phenomena of flocculation and precipitation are really quite similar. It would seem to be one of those points between physical and chemical forces which have been sharply marked in the past, but which are now fast disappearing as these two sciences are coming closer together.

If two small grains of clay, suspended in water, come close together they may be attracted to each other or not, according to the potential of the water particles on the surface of the clay. If the potential of the surface particle of water is less than the particle in the interior of the mass of liquid, there will be surface tension, and the two grains will come together and be held with some force, as their close contact will diminish the number of surface particles in the liquid. If, on the other hand, the potential of the particle on the surface of the liquid is greater than of the particle in the interior of the mass, the water surface around the grains will tend to enlarge, as there will be greater attraction for the water particles there than in the interior of the mass of liquid, and the grains of clay will not come close together and will even be held apart, as their close contact would diminish the number of surface particles in the liquid around them.

This hypothesis would seem to be easy to prove experimentally, and it was hoped that this could be done in time for this report, but there has not been time, although the apparatus has been ready for some months.

Much interesting work has been done by Hilgard, Brewer, and Carl Barus on this matter of flocculation. They all assume a chemical hydration of the fine particles of clay as an important factor in the suspension of the clay in water, and of de-hydration by salt or lime, in the flocculation of a turbid liquid. While such hydration and de-hydration may occur, it does not seem at all necessary for the continued suspension and almost indefinite suspension under ordinary conditions of fine clay particles in a turbid liquid. I can not agree with Brewer that clay particles are ultra-microscopic, although they are exceedingly small and very difficult to define. In a turbid liquid which has stood for several weeks and is only faintly opalescent, a drop of the liquid carefully evaporated on a cover glass, ignited and stained, as in ordinary bacteriological examinations, will show particles under an oil emersion objective, not very sharply defined to be sure, under such a high power, but still of measurable size, ranging from about $\frac{1}{10}$ of a space of my eye-piece micrometer to about $\frac{1}{2}$ of a space. The lower limit would give a value of .0001 millimeter and as this has been verified a number of times in turbid liquids which have stood so long as to be only faintly opalescent, I have assigned this as the lowest limit of my "clay" group, pending further and more exact determinations in which a turbid liquid shall be examined at frequent intervals during subsidence, and where precautions have been taken to destroy and exclude bacteria.

Fine dust and ashes, and even filings of metals, remain in suspension in the air for days and even months in very apparent clouds or haze, although they may be a thousand times heavier than the surrounding air. Particles of clay, no smaller than the limits which have been assigned, should remain in suspension in the much heavier fluid water for an indefinite time, for the volume or weight of a sphere decreases so much more rapidly in proportion than the surface, that there is relatively a large amount of surface area in these fine particles and a great deal of surface friction in their movement through a media, and they would settle very slowly. This is clear from the following calculation:

The volume of a sphere $= \frac{4}{3}\pi r^3$
The surface of a sphere $= 4\pi r^2$

The volume or weight decreases proportionately faster than the surface area. For, consider a sphere of a radius of one inch. The volume will be $\frac{4}{3}\pi 1^3$ and the surface $4\pi 1^2$. If, now, this sphere be reduced in size until the radius is $\frac{1}{100}$ of an inch, the volume will be $\frac{4}{3}\pi \frac{1}{1000000}$ and the surface of the sphere will be $4\pi \frac{1}{10000}$.

If we assume now the mean diameter of several of our separations in a mechanical analysis we will have the following values:

Diameter 1.5 millimeters, fine gravel.
Diameter 0.075 millimeters, very fine sand.
Diameter 0.00255 millimeters, clay.

If we assume the volume, or weight, of the gravel to be unity, then for very fine sand—

The volume decreases in the ratio 1 : 0.000125:
The surface decreases in the ratio 1 : 0.2556.

For clay—

The volume decreases in the ratio 1 : 0.000000004853.
The surface decreases in the ratio 1 : 0.000286.

If the lowest value given above is assumed for the diameter of the clay particle (.0001 millimeter) the ratio would be, of course, still more striking. As it is, the relatively large surface area of these fine particles would allow them to subside only with extreme slowness, and it would probably seem that under ordinary conditions, in which the mean daily range of temperature is 20°, the mean monthly range 50°, and the yearly range 100° F., that the ordinary convection currents, induced by this normal change of temperature, would be sufficient of itself to keep these fine particles in suspension in the liquid for an indefinite time, as it is known that currents of air keep fine particles of dust in suspension. It does not seem as though it were necessary to consider the chemical hydration hypothesis to explain the suspension of fine particles in water; nor the de-hydration hypothesis to explain the flocculation of clay, when the grains, under a low potential, can come within the sphere of their mutual attraction and fall or rise together in a loosely united mass.

This matter of flocculation has a most important bearing on the arrangement of the soil grains, and the relation of the soil to water. It will be remembered that there is, on an average, about 50 per cent. by volume, of empty space within the soil. This empty space is divided up by a vast number of grains of sand and clay. If these grains are evenly distributed throughout the soil, so that the separate spaces between the grains are of nearly uniform size, water will move more slowly through the soil than if the grains of clay, through flocculation, adhered closely together and to the larger grains of sand, making some of the spaces larger and others exceedingly small.

The movement of water through capillary tubes is according to the *fourth* power of the radius. If we have ten capillary tubes of equal size, and ten other tubes with the same total area of cross section, but with one of the tubes large and the other nine tubes exceedingly small, water will move much faster through these tubes of uneven size than it will through the others.

We have, then, this principle to work on in the improvement of soils. In a close, tight clay in which water moves slowly, the continued use of lime may cause flocculation; the grains of clay will move closer together, leaving larger spaces for the water to move through. This is undoubtedly the trouble in the clays of the Potomac formation in Maryland, the grains are very evenly distributed and the flow of water is so extremely slow that the soil is practically impervious to water. In such a soil a rapidly growing plant might perish for lack of sufficient water supply, when it was shown by analysis that the soil contained a large amount of water. The movement of water would be so slow that the soil could not supply the plant with water rapidly enough for its need, and the plant would suffer for water as in a light sandy land.

On the other hand, there are soils in which the clay is held so closely to the grains of sand as to give the soil the appearance and properties of a sandy soil, although there is as much clay present as there is in many of the distinctively "clay" lands. This will be shown very clearly in speaking of the Wedgefield, S. C., soils, in another place. We will speak of this matter more at length when we come to speak of the application of these principles to the improvement of soils. Most of our work has been on the determination of the approximate number of grains per gram, to show how much the empty space in the soil has been divided up; and this matter of the determination of the arrangement of the soil grains in their natural position in the field has hardly yet been taken up.

This movement or rearrangement of the soil grains could readily occur in a soil, even if the soil were only slightly moist, for the diameter of the fine silt and clay particles would be much less than the mean thickness of the film of water in the soil, and they could move freely as though they were immersed in a relatively deep fluid. The forces which move them, as will be shown later, are changing moisture content and possibly changing atmospheric pressure, while the condition which determines their close contact will be the surface tension or potential around the soil grains; and this can be changed, as we have seen, by the different fertilizing materials, when the grains will assume a closer or a looser arrangement.

THE VOLUME OF EMPTY SPACE IN SOILS.

There is, on an average, about 50 per cent. by volume of empty space in soils. The amount in the soil proper will vary with the state and stage of cultivation, but the empty space in the undisturbed subsoil will remain fairly constant. The amount of space in the soil may be found by completely filling a short depth of a known volume of soil with water. The weight of the soil before and after the introduction of the water will give the weight of water or the volume of the space. Or the amount of empty space may be found by calculation from the weight of a known volume of soil and the specific gravity. The weight of a known volume of soil in its natural position in the field can be determined as follows: An iron or brass tube, about 2 inches in diameter and 6 or 9 inches long, is driven into the ground to a depth of 6 inches. The tube is then dug out, a knife being passed under the lower edge to cut off the cylinder of soil in the tube. The soil is then carefully removed, dried, and weighed.

From the weight of soil and the volume of the tube, the volume of empty space may be found by the following formula:

$$S_1 = \frac{\left(V - \frac{W}{w}\right) \times 100}{V}$$

Where S_1 is the per cent. by volume of empty space, V is the volume of the tube in cubic centimeters, W is the weight of soil in grams, and w is the specific gravity of the soil.

At first a piece of 2-inch boiler tube was used for taking the samples, one end of the tube being turned off in a lathe to give a good cutting edge. It was found, however, that the friction against the inside of the tube forced the cylinder of soil down a little so that it was feared that the weight of soil would be too light. Such a tube was used in the South Carolina work. In the more recent work a brass tube has been used, which has a clock spring securely soldered in one end, which is turned off in a lathe to give a good cutting edge of hard steel. The area inclosed by this cutting edge has been accurately determined. The tube is 9 inches long, with a mark on the side of the tube 6 inches from the cutting edge, and the tube is driven down into the soil until this mark is even with the surface of the ground. The advantage of this arrangement is that the clock spring cuts out a cylinder of soil of a definite area of cross section and friction is reduced to a minimum, while the soil can be readily removed from the tube. The sampling may be done for every 6 inches down for any desired depth.

The per cent. by volume of empty space varies from about 35 per cent. in the undisturbed subsoil of a coarse, sandy land to 65 or 70 per cent. in the subsoil of a strong clay land.

In "How Crops Feed," Johnson gives the weight of a cubic foot of sandy land at 110 pounds, and a cubic foot of clay soil at 75 pounds. Assuming 2.65 as the specific gravity of the soils, this would give about 34 and 55 per cent. by volume of empty space, respectively, in these soils.

The term "light soil" is thus commonly applied to that which actually weighs a good deal more than what is called a "heavy soil." The terms refer to the texture of the soils and the ease with which they can be worked.

The amount of space has been determined in a number of subsoils in South Carolina, in their natural position in the field, including a wide range of soil formations. The per cent. by volume of empty space is given in the following table:

Empty space in South Carolina subsoils.

(Per cent. by volume.)

78.	Wedgefield (sandy land)	41.80
66.	Gourdins	42.82
57.	Sumter	44.10
80.	Lesesne	46.41
57*a*.	Sumter	47.70
69.	Gourdins (Mr. Roper)	49.74
64.	Lanes	50.00
74.	Wedgefield ("Red Hill" formation)	50.08
69*a*.	Gourdins	50.25
58.	Charlotte, N. C	52.05
71.	Gourdins ("bluff land")	55.40
58*a*.	Charlotte, N. C	57.19
76.	Wedgefield ("gummy land")	58.46
76*a*.	Wedgefield ("gummy land")	61.54
42.	Chester ("pipe clay")	65.12

The amount of empty space has been determined in only a few of the Maryland soils, with the following results:

Empty space in Maryland subsoils.

(Per cent. by volume.)

246.	Truck land, Tick Neck	37.29
246.	Truck land, Shipley	39.00
568.	Truck land, Armiger	41.25
478.	Wheat and late truck, Shipley	42.72
567.	Truck land, one mile west of Armiger	43.90
579.	Truck land, Rock Point	45.54
592.	Barren Potomac clays	47.19
599.	Wheat land, South River	51.48

As opportunity offers, these determinations will be made in other parts of the state, especially in the heavier soils of western Maryland.

The following values have been used in all of our work, the specific gravity in all cases being taken as 2.65:

Per cent. by volume of space.	Weight of unit volumes of soil.		Per cent. by weight of water. Saturation.
	1 cc. grams.	1 cu. ft. grams.	
40	1.5900	45.020	20.10
45	1.4575	41.260	22.41
50	1.3250	37.510	27.42
55	1.1925	33.750	31.55
60	1.0600	30.044	36.14
65	0.9175	26.334	41.22

A soil having 40 per cent. by volume of empty space will hold 20.10 per cent. by weight of water when all the space within the soil is filled. A soil having 55 per cent. by volume of empty space will hold 31.55 per cent. by weight of water when all the space within the soil is completely filled.

This amount of empty space in the soil is an important factor in the movement of water through the soil and in the drainage of land.

It will be seen that when the soils are saturated the sandy land has a capacity of only about two-thirds or one-half the amount of water which the clay soils can hold. When these soils are saturated the water may move off through the clay soil more easily and more rapidly, notwithstanding the smaller size of the separate spaces, because the clay soil will hold more water than the sandy land. Where the soils are short of saturation these conditions are reversed, as the size of the separate spaces very largely determines the rate of flow, and the spaces within the sandy land being larger water flows through more readily.

The size of the grains has an important value in determining the amount of empty space within the soil. Most of our soils are of sedimentary origin, or are derived from rocks which are themselves of sedimentary formation. The material out of which the soils are formed has been deposited from suspension in water. The larger the size of the grains the closer the arrangement will be, so that in a coarse sandy soil there will be less empty space than in a fine clay. If cannon balls were poured into a measure and allowed to settle under water they would take up a very close arrangement, because their volume or weight is large in proportion to their surface area, and their weight is sufficient to overcome the resistance of the water and the resistance offered by the adjacent balls. If fine road dust be poured into a similar measure and allowed to settle under water, the volume or weight of the grains is so small in proportion to the surface area that there will be relatively a great amount of friction as the particles descend, so the descent will be extremely slow. Then as the particles touch, the weight of each is not sufficient to overcome the friction against the sides of the adjacent particles and they do not settle into the same compact and close arrangement as the heavier cannon balls, but take up a looser and a lighter arrangement, leaving more empty space. To compact a quantity of this material into a space occupied by an equal weight of the cannon balls would require a very considerable pressure to overcome the resistance offered by the friction between the surfaces of the adjacent grains.

This will account for the large amount of space in clay soils of sedimentary origin, or in clay soils derived from the disintegration of sedimentary rocks; but it is an interesting fact that these same relations hold with soils derived from crystalline rocks. It can hardly be supposed that just 40 per cent. of all such rocks as produce sandy soils have been dissolved out in one case, while 55 or 60 per cent. have been dissolved and leached out of other rocks which give clay soils on disintegration.

It seems much more probable that on disintegration the grains are pushed apart and the volume of material is increased. It must be remembered that in the case of clay soils there is an immense amount of surface area in proportion to the amount of material, and that any forces that would tend to push the grains apart would have, relatively, great effect. It is very easy to show that there are forces within the soil that would tend to push the grains apart, as is shown in the swelling of clay when wet. It is probable that the tension or potential on the surface separating the soil and water will largely determine how close the grains may come, as in the phenomenon of flocculation already described. If the grains are closer than a certain distance apart there will be this tendency for them to move further apart. It will also be shown in another place that the soil grains are very constantly moving back and forth through the influence of changing climatic conditions, changing water content, and, probably, with changing chemical composition of the soil moisture. It will probably be found that in the disintegration of rocks the fine material swells and occupies a larger volume than before. The finer the material the more surface there is for the forces to act against to keep the grains further apart, and the greater the resistance against their taking up a closer arrangement.

Another property of clay may be mentioned here, due to this function of the small size of the grains. In a symmetrical arrangement of the grains in a soil containing 47.64 per cent. by volume of empty space, each grain will touch the surface of six adjacent grains. There is a certain amount of surface attraction between these particles.

If the grains are large they still only touch at six points, and the weight of the grains is sufficient to overcome this slight surface attraction. A lump of wet sand will fall apart as it dries, for it is bound together by the contracting power of the film of water which surrounds it, and when this is removed by evaporation the weight of the grains is sufficient to overcome the surface attraction of the relatively large and heavy particles, and they fall apart.

If the grains are very small, like grains of clay, the surface attraction of the grains is sufficient to bind the mass into a compact lump when dry; for while there are still only six points of contact for any one grain, there are many more grains and so many more points of contact in a given weight of material. If the size of the grains was still further reduced to molecular proportions the mass would assume the hardness and rigidity of a single grain of sand or clay.

When a dry, compact mass of clay is wet with water the water forces itself in between the grains and forces the grains themselves apart, and the clay swells; but as the grains are held together by their own surface attraction, which is relatively very much greater than with the grains of sand, as well as by the contracting power of the film of water which surrounds them, and as the water keeps them from actual contact and free to move or slide over one another, the mass assumes a *plastic* condition characteristic of clay when wet. It would seem that most of the peculiar functions of clay may be explained by purely physical laws, and that they are very largely due to the one function of the small size of the grains. It is probable, therefore, that if quartz could be powdered so fine that the diameter of the grains would come within .005–.0001 millimeter, they would have all the characteristic properties of clay, forming a plastic mass when wet and a hard, compact lump when this wet mass was dried. It would probably absorb water quite as readily as clay does, for it must be understood that this peculiar absorptive property of clay is due to the relatively large extent of surface area and to the extremely small size of the capillary spaces between the grains, and not to any inherent "stickiness" or absorptive power of the grains of clay, which are claimed by some to be porous and to "suck up water as a sponge." The slight film of moisture on the surface of a small watch glass is difficult to get rid of, and is sufficient in quantity to vitiate a careful analysis unless it is always driven off before the glass is weighed. This glass has hardly more than 2 or 3 square centimeters of surface per gram, but if this gram of glass were ground up as fine as the heavy clay of a limestone formation, it may have as much as 5,000 square centimeters of surface area per gram, and each unit of surface may attract as much moisture as before, so that the amount of moisture which the soil can hold when air-dry may amount to several per cent. of the weight of soil.

THE RELATION OF GEOLOGY TO AGRICULTURE.

There are a number of well-marked types of soil in Maryland, some suited to grass and wheat, others to wheat but rather light for grass, others to tobacco, truck, or left out as barren wastes. The texture and general appearance of these soils differ very much, so that one can tell at a glance to what kind of crop each of these types is best adapted. It will be shown that from this difference in texture, which is so very apparent to the eye, there is a marked difference in the relative rate with which water moves within the soil, and the ease with which the proper amount of water may be maintained and supplied to the crop.

As crops differ in the amount of water which they require, and in the amount of moisture in the soil in which they can best develop, this difference in the relation of these soil types to water probably accounts for the local distribution of plants.

In greenhouse culture the same kind of soil is used for all kinds of plants, but great judgment is required in watering the plants. Some plants require a very wet soil, others must be kept quite dry. The amount of water required will not be the same at different stages of development of the plant. During the earlier growing period the soil is kept quite wet, but during the fruiting or flowering period the soil is kept much drier. Each class of plants requires, in this way special treatment, and it is through this judicious control of the water supply in the soil and the temperature of the air that the best development of each class of plants is attained.

Our soil types, therefore, in having different relations to the circulation of water, partake somewhat of these artificial conditions in greenhouse culture, and on each of them certain classes of plants will find conditions of moisture best suited to their growth and development.

Our soils have been formed from the disintegration, or decay, of rocks. The rocks are made up of different minerals, the most common of which are quartz, feldspar, and mica. The kind of rock is determined by the kind and relative amount of each of these minerals of which it is made. When the rocks decay, part of the minerals, or the cementing material, is dissolved and carried off, and many of the minerals themselves are changed. Now the texture or the relative amount of sand and clay contained in the soil resulting from the disintegration of these rocks, *in situ*, will depend upon the kind of rock, that is, upon the minerals of which it was composed.

The soils of northern-central Maryland have been formed from the disintegration, *in situ*, of the crystalline and semi-crystalline rocks of the Piedmont Plateau.

The material resulting from the disintegration of these rocks is slowly washed away and carried off by streams and rivers. As the current of water becomes slower near the sea the sand is deposited along a rather narrow shore line, while the finer particles of clay are carried further and deposited over wider areas. The conditions where some parts of this material are being deposited may be favorable to the growth of coral and of various kinds of shellfish, so that their remains accumulate in beds of great thickness, giving the material for the limestone of the present day. These sediments are thus assorted out by subsidence in water of different velocities, as though they had been sifted and the different grades of material spread out over wide areas. The soils of southern Maryland and the Eastern Shore are of this unconsolidated sedimentary material, which is still in the first stages of rock formation.

In former geological periods similar sediments, having been slowly deposited in beds of great thickness, were converted into rocks, forming sandstones, limestones, and shales; the sandstone, where the coarser material has been deposited near the shore; the limestone, where the shells have accumulated; and the shales, where the fine mud has been spread out over a wide area of still water.

It is from the disintegration of these "sedimentary" rocks, which have since been raised above the surface of the water and folded into a succession of mountain ranges, that the soils of western Maryland have been formed. There are the limestone valleys, where shellfish were once abundant, and where now is a strong clay soil well adapted to wheat, composed of what was once the impurities of the limestone rock, which has been left as the more soluble lime has been dissolved and carried away; the sandstone ridges, some of which, resisting decay, form the mountain ranges, while others, made of finer grains of sand and less firmly cemented together, form some of the fertile hill and valley lands; the shales, in which the grains of mud were so extremely small that they have not thoroughly disintegrated in this State, and the soil is filled with fragments of the rock and supports but a scanty mountain pasture.

Geology defines the limits and areas of these different formations and of these different rocks, and as I have shown that these rocks determine the texture of the soil, a thorough and detailed geological map of the state should answer for a soil map. Any one familiar with the texture of the soil, or kind of soil, formed by the disintegration of granite, gabbro, and the different kinds of limestones, sandstones, and shales, should be able to tell by a glance at the map the position and area of each kind of soil. Each color on the map would represent a soil formation which under prevailing climatic conditions would be best adapted to a certain crop.

The wheat, tobacco, truck, and barren lands of southern Maryland are each confined to certain different geological formations for their best development, and a geological map of this portion of the state should show the area and distribution of the lands best adapted to these crops.

There is usually some marked and distinctive botanical character in the herbage of these different soil formations. We have pine barrens, white oak lands, black jack lands, chinquapin lands, grass lands, wheat lands, and truck lands. These names convey a very good impression of the character and texture of the soil, and they should be more generally used. When a soil formation is spoken of as black jack land, the name conveys a distinct impression of the kind of soil, for a soil must have a certain characteristic texture to produce such growth.

SOIL TYPES.

The soils of any wide locality, especially in our Eastern States, appear, at first sight, to offer an endless field of research in the great variety often seen on a single farm and in the same field; but a more comprehensive view of the matter will show this to be due to local causes, which have mixed up and modified the original soil formation. These local modifications may be neglected for the present, until the general features of the representative soils of the region have been worked out. The characteristic properties of great soil formations, or soil types, must first be determined, and then more detailed work may be done in examining soils of local interest.

Why will not truck, tobacco, wheat, and grass grow equally well on all soils? What are the characteristic properties of a good wheat land, of the best tobacco soil, of the best grass land, of the best land for market truck? What is it in the appearance of the soil which enables a farmer to place it in one or the other of these classes? It is not until this problem has been mastered and these very evident differences in the soils have been explained, that the real and full value and application of the chemical determination in plants and soils will be seen. As a rule, the chemical analysis of a soil will not enable a farmer to determine to what his farm is best adapted; but, on the contrary, the farmer, from his experience and judgment, must inform the chemist of this point, and must tell him of the strength and condition of the land.

A large number of samples of soils and subsoils, of representative agricultural value and importance, have been collected in Maryland, and these samples have been classified according to their agricultural value and their geological origin. The soils of all the principal agricultural regions of the state can thus be classified under not more than fifteen different types, and a number of these do not differ materially in their agricultural value, but are given a separate place on account of the distinctive geological formations. The different types will be described when we come to speak of the mechanical analysis of the soils.

THE INTERPRETATION OF THE MECHANICAL ANALYSIS OF SOILS.

THE METHOD.

The method which has been employed for the mechanical analysis of soils is substantially Johnson and Osborn's "beaker method." Twenty grams of the air-dry material were rubbed up in a mortar, with successive quantities of water, and a few drops of ammonia to prevent flocculation, until the liquid on standing a moment became quite clear and the soil remaining in the mortar contained no grains smaller than .05 millimeter, as shown by microscopic measurements. A rubber pestle was used so that the soil grains should not be broken. A very good pestle can be made by putting a rubber cap, such as is used on the ends of chair legs or crutches, over the handle of a porcelain pestle. The coarse material in the mortar was then dried and sifted through a series of sieves with round holes, 2, 1, and .5 millimeters in diameter, and through two pieces of bolting cloth with square holes, having an aperture, respectively, of very nearly .25 and .1 millimeter, the holes being very uniform in size, as shown in the microscopic measurements. The turbid liquid, which was poured off from this coarse material, was allowed to settle until all grains larger than .05 millimeter had settled. The turbid liquid was then poured off and the material in the bottom of the beaker was stirred up with a fresh quantity of water, and material larger than .05 millimeter was allowed to settle as before. This was repeated until all material finer than .05 millimeter had been removed. The remaining coarse material was thrown in with the "very fine sand." Other separations were made in the turbid liquid, until all grains larger than .005 millimeter were removed, and everything smaller than this was included in the clay group. The turbid liquid containing the last separation was carefully measured in a liter flask, and 100 cubic centimeters of this turbid liquid out of every liter was evaporated to dryness in a porcelain dish. The finest separations, including the silt, fine silt, and clay, were all ignited and cooled in a desiccator before weighing. The coarser grades of sand were not ignited as the amount of moisture which the air-dry material contained was found to be extremely small and within the limit of error of such an analysis. .0001 millimeter is taken as the smallest limit of the clay group, because it is believed that practically all the clay particles are larger than this.

There are, relatively, very wide limits in this clay group, as the largest diameter is fifty times larger than the smallest. This is of very great importance, as the extremely small size of the grains gives a very large number of grains for a given weight of material, and the aggregate extent of surface area of this vast number of particles is usually larger than of all the other grades combined. It would be very desirable to have a greater number of separations, an infinite number if this were possible, so as to have very narrow limits between the diameters and so that the diameters of all the particles in a single separation shall be very nearly of the same size. It is practically impossible, however, with this beaker method to make more than the number of separations which have been adopted, as it takes a long while to make the separations. This clay group is of so much importance, therefore, that a very slight difference in the value of the diameters will give widely different absolute values in the determination. It is impossible, however, to expect that the absolute number of grains in one gram of soil could ever be determined, and if they could be, the science of mathematics is not refined enough to deal with them as we wish. Comparative results can alone be expected, and one of the essential things in this is to have the mechanical analysis made by methods which give fairly uniform results, while the number and value of the separations, and especially of this clay group, be always the same.

In the mechanical analysis, when any of the separations were allowed to remain some time to settle out, the material in the bottom of the beaker was rubbed up in the mortar with a rubber pestle, as it was liable to cake on standing.

APPROXIMATE NUMBER OF GRAINS IN ONE GRAM OF SOIL.

Having determined the amount of empty space in the soil by a method already given, it is important to know how much this space has been subdivided. There is about half a cubic foot of empty space in a cubic foot of soil, and it is evident that if this space formed one large cylinder a large body of water would flow through with great rapidity. It is also evident that water will flow through this space more and more slowly the more it is subdivided. The amount of subdivision of the space will depend upon the number of grains in the soil, and somewhat upon their arrangement. The approximate number of grains per gram can be calculated from the mechanical analysis of the soil by the following formula:

$$\frac{a}{\frac{\pi (d)^3 \omega}{6}} \div A$$

Where a is the weight of each group of particles, d, the mean diameter of the particles in the several groups, A is the total weight of soil, and ω is the specific gravity of the soil.

In using the formula the per cents are used as grams, thus, if there were 20 per cent. of silt this would be taken as 20 grams, and if the results of the analysis added up 97 per cent. the whole weight of soil would be taken as 97 grams. The diameter (d) is taken as the mean of the extreme diameters given for any group. For instance, for the silt this would be .03, which is assumed to be the diameter of the average sized particle.

The specific gravity has been taken as 2.65 in all the determinations which have been made. This value was originally selected from a statement by Johnson, in "How Crops Feed," page 159, of some determinations by Schöne, and our own results have shown no very good reason for changing this unless the value 2.70 be substituted, or unless the specific gravity of each soil be specially determined for insertion in the formula, which hardly seems necessary at the present stage of the investigation.

The following table gives the specific gravity of some of our type subsoils, the type sample being made up in most cases of samples from a number of localities:

Specific gravity of type subsoils.

No.	Soil.	Air-dry.	Ignited.
276	Pine barrens	2.6388	2.6485
284	Truck	2.6259	2.7016
286	Tobacco	2.6151	2.7100
290	Oriskany	2.6550	2.6583
280	Wheat	2.5949	2.7109
278	River terrace	2.6229	2.6855
181	Triassic red sandstone	2.7115	2.7759
238	Catskill	2.6875	2.7201
289	Shales	2.6625	2.7302
288	Helderberg limestone	2.6978	2.7385
	Average	2.6512	2.7079

Specific gravity of separations.

Diameter.	Conventional names.	Specific gravity.
mm.		
2-1	Gravel	2.6469
1-.5	Coarse sand	2.6547
.5-.25	Medium sand	2.6476
.25-.1	Fine sand	2.6594
.1-.05	Very fine sand	2.6807
.05-.01	Silt	2.7337
.01-.005	Fine silt	2.6642
.005-.0001	Clay	2.8368

The specific gravity of the silt and clay groups in the list of separations is quite high, and the duplicate results, of which the mean is given, were rather wide, for what reason has not yet been determined, unless it is due to chemical changes of the iron compounds in the ignition of the material.

It must be remembered that the results obtained by the use of this formula of the number of grains per gram have only approximate values, and can only be used in comparative work.

The approximate number of grains per gram will be given with the results of the mechanical analysis of the soils. One table will be given in detail, showing the approximate number of grains in each separation in one gram of subsoil, from which it will be seen that the extremely small diameter assigned to the clay group has an important value, as the vast number of grains in this and in the fine silt practically determines the number of grains per gram.

THE ESTIMATION OF SURFACE AREA OF SOIL PARTICLES.

The approximate extent of surface area of the soil grains in one gram of soil can be calculated from the foregoing by the following formula:

$$\pi (d)^2 n$$

in which d is the mean of the diameters of any group in centimeters, and n is the number of particles in the group.

The following logarithmic constants have been used in the calculation of the results, using 2.65 in all cases as the specific gravity of the soil:

Diameter. (d)	Approximate number of grains.	Surface area.
	(log.) $\frac{\pi(d)^3 w}{6}$	log. $(d)^2\pi$
cm.		
.15	$\bar{3}.6703$	$\bar{2}.8493$
.075	$\bar{4}.7674$	$\bar{2}.2473$
.0375	$\bar{5}.8641$	$\bar{3}.6451$
.0175	$\bar{6}.8711$	$\bar{4}.9831$
.0075	$\bar{7}.7674$	$\bar{4}.2473$
.003	$\bar{8}.5734$	$\bar{5}.4513$
.00075	$\overline{10}.7674$	$\bar{6}.2473$
.000255	$\overline{11}.3616$	$\bar{7}.3101$

CALCULATION OF THE RELATIVE RATE OF MOVEMENT OF WATER THROUGH SOILS.

It has been stated that the relative rate of movement of water through soils will depend upon how much space there is in the soil; upon how much this space is subdivided, *i. e.*, upon how many grains of sand and clay there are in the soil; upon how these grains are arranged, and upon how this skeleton structure is filled in and modified by organic matter.

It will be assumed for the present that the grains have the same mean arrangement in all the soils and the influence of the organic matter will be assumed to have the same value in all cases, and this will also be neglected for the present. Where the rate calculated from the mechanical analysis of the soil differs from the observed rate determined experimentally, it may be assumed that the grains have a different mean arrangement in the two soils or that the influence of the organic matter is not the same.

There will evidently be one space, or opening, into the soil for every surface grain, and the approximate number of grains, or of openings, on a unit area of surface may be found by the following formula:

$$N = \left(\sqrt{\frac{M \times W}{V}}\right)^{\frac{2}{3}}$$

Where N is the number of grains, or openings, on one square centimeter of surface, M is the approximate number of grains in one gram of soil, W is the weight of soil, V is the total volume of the soil grains and the empty space.

If the grains are assumed to be symmetrically arranged and the spaces between them cylindrical in form, the radii of the spaces can be found by the following formula:

$$r=\sqrt{\frac{V_1}{\pi N L}}$$

Where r is the radius of a single space, V_1 is the total volume of the empty space, N is the number of grains or spaces on one square centimeter of surface, and L is the depth of the soil.

If the space within the soil is completely filled with water the relative rate of flow of water through the soil will be according to the fourth power of the radius of a single space multiplied by the number of spaces on the unit area of surface, as shown by the following formula:

$$T_1=\frac{N\,(r)^4\,T}{N_1\,(r_1)^4}$$

Where $N-N_1$ are the number of spaces, and $r-r_1$ are the radii of single spaces in the respective soils, and $T-T_1$ the time required for a unit volume of water to flow through the soils under the same head or pressure.

The space within the soil is rarely filled with water in agricultural lands, but the most favorable amount of water for the soil to hold, as Hellriegel and others have shown, is from 30 to 50 per cent. of the total amount of water the soil could hold if all the space within it were filled.

If the space within the soil is only partly filled with water, as in most arable lands, the water will move in a thin film surrounding the soil grains and according to the fourth power of the thickness of the film. The mean thickness of the film surrounding the soil grains may be theoretically determined by the following formula, which is based on the conception that the film is cylindrical and of uniform size throughout:

$$t=r\left(1-\sqrt{\frac{s}{s+p}}\right)$$

Where s is the per cent. by weight of water which the soil will hold when the empty space is filled with water, p the per cent. of water actually contained in the soil, r the radius of a single space, and t the mean thickness of the film surrounding the soil grains.

The relative rate of flow of water through the soils will then be according to the following formula:

$$T_1=\frac{N\,(t)^4\,T}{N_1\,(t_1)^4}$$

It must be remembered that these formulæ give only approximate and comparative values for comparing one soil with another. The structure of the soil is altogether too intricate to expect ever to obtain absolute values.

DETERMINATION OF THE ACTUAL RATE OF FLOW OF WATER THROUGH SOILS.

A method has been given, based on theoretical considerations, for the calculation of the relative rate of movement of water through soils from the mechanical analysis. The following method has been used to determine the actual rate of flow of water through the soil in its natural position in the field, and described in the Experiment Station Record, volume 3, No. 10 (May, 1892), page 68.

To determine the actual rate of circulation of water in the soil or subsoil in its natural position in the field, a hole should be dug, and the soil and subsoil on one side removed to the depth at which the observations are to be made. A column of the soil or subsoil, 2 inches or more square, and 4 or 5 inches deep, is then to be carved out, and a glass or metal frame, a little larger than this and 3 or 4 inches deep, is slipped over the column, and melted paraffine is then run in to fill up the space between the soil and the frame. The soil is then struck off even with the top and bottom of the frame, a piece of linen tied over the under side, or what is better, the frame can rest on some coarse sand or gravel, contained in a funnel, to prevent the soil from falling out and to provide good drainage for the water to pass through. A section of the frame can then be placed on the top and secured by a wide rubber band, or otherwise, and the time noted which is required for a quantity of water to pass through the saturated soil. The initial depth of water over the soil must be the same in all the experiments. Root-holes and worm-holes are to be avoided, and these are particularly troublesome in clay lands. The amount of space should be determined in this or in another sample, as described in a previous section.

These determinations are usually made out in the field. They are rather troublesome to make, especially as most of them have to be made in different parts of the state, and they require considerable time; only a few of these determinations have been made in the soils of Maryland as most of our time has necessarily been occupied in the preliminary work of securing samples from as many widely separated localities as possible, and making the mechanical analysis of the same to give material and data to work on. With this in hand the field has all to be gone over again, to study the texture of the soil and the arrangement of the soil grains, and this will involve the determination of the actual rate of flow of water through the soils in their natural position in the field. The preliminary work had to be done first so that this work would have a meaning. The actual determinations which have been made will be given with the mechanical analysis of the soils.

Considerable work has been done on the flow of water through air-dried soils, loaded into tubes. Eight-inch Argand lamp chimneys are used, with a piece of muslin tied tightly over one end. A mark is placed on the side of the tube 6 inches above the lower end. The chimneys are about 2 inches in diameter, and the capacity of the tube up to the 6-inch mark is about 300 cubic centimeters. The tube is filled with 6 inches in depth of soil by gently tapping the bottom of the tube. The tube is weighed before and after the soil is introduced, when the weight and volume of the soil and the volume of the empty space may easily be calculated if the specific gravity of the soil is known. 2.65 has, in all cases, been used as the specific gravity of the soil. From this data and the mechanical analysis of the soil the relative rate with which water will move through the soil can be calculated.

The soil should then be saturated with water and the tube supported so that the muslin just touches the surface of the water, contained in a vessel below, to reduce any tension at the bottom of the soil. What is better than this is to remove the muslin from the bottom of the tube before the soil is saturated, and place the tube on some fine gravel or coarse sand, contained in a funnel, to keep the soil from falling out, but to provide good drainage for the water. When the soil is saturated and water is flowing from the funnel, an inch in depth of water (41 cubic centimeters) is then carefully poured on the soil and the time noted that is required for it to pass through the soil, or to displace an equal quantity of water from the tube. The initial depth of water in these determinations is 1½ inches, and the time is noted which is required for the water to fall one inch, or to within ½ an inch of the surface of the soil.

It is extremely difficult to fill these tubes in this way with air-dry soil without a separation of the finer particles into separate layers, which would retard the flow of water. The tubes often have to be filled several times before they are uniform in appearance. In view of this difficulty, it is much better to slightly moisten the soil before filling into the tube. But as the amount of moisture affects the arrangement of the grains and the rate of flow, we have used 3 per cent. of moisture in all cases. To mix this uniformly and easily with the soil, rather more than the requisite quantity is poured on to the soil and covered over with the dry material and let stand for a number of hours to soak in. After this it can be thoroughly and easily mixed by hand without the formation of lumps. After thorough mixing it is allowed to stand, if necessary, until the soil contains only 3 per cent. of water, and it is then thoroughly mixed again and loaded into the tube.

This method is not so reliable as where the soil is taken in its natural position in the field, for the effect of drying and the necessary preparation of breaking down the lumps which have been formed in drying, before loading into the tube, may very materially modify the arrangement of the soil grains. Still, when it is remembered, that in plowing the soil is turned over and allowed to fall back as it would fall into the tube and is often quite completely dried out during this process, and that this does not very materially change the arrangement of the soil grains if done intelligently, perhaps these objections are not as serious as they would appear at first sight, and that soil samples brought from a distance can be compared in this way. It would be very desirable if a method could be devised for determining the actual rate of flow of water through soils short of saturation, when they contained, say, 8 or 10 per cent. of moisture.

There is another difficulty encountered in this method, that where the saturated soils are left standing the rate of flow becomes slower and slower, probably caused by a rearrangement of the soil grains, due to the repeated quantities of water changing the composition of the soil moisture. For this reason it is better to pass air through the soil than the denser fluid water. A known quantity of air can be passed through the soil at a definite pressure and the time noted, as in the case of water. This is a much more satisfactory method, as there are no chemical or physical changes to be feared.

THE RELATION OF SOILS TO WATER.

The samples which are to be described have all been very carefully collected by the writer. The early sampling was done with a spade, but most of the Maryland soils have been collected with a 2-inch wood auger, one end being fitted for a small iron pipe which could be inserted at will for a handle. The auger can readily sample to a depth of 18 inches from the surface, and besides the much greater convenience in carrying and in sampling over the spade, it brings up a complete sample to the desired depth, the whole of which is carried to the laboratory, and it is not necessary to mix it in the field to select a small sub-sample, as must be done when the spade is used.

The sample of soil is taken down to the change of color, or, when this is not apparent, to a depth of 6 inches, and the subsoil is taken from below this to a depth dependent upon the nature of the material, but usually to a depth of 18 inches from the surface.

The subsoil alone has been analyzed and examined in most cases, for the soil has been subjected to artificial conditions and manuring, which might materially modify the results of the investigation, and besides, the undisturbed subsoil practically determines the movement of water, and it is the subsoil, rather than the soil, upon which the practical farmer bases his judgment of the strength and character of the land.

The samples have been taken from as widely different localities as possible, and from many different soil formations, and they are accompanied, as far as possible, with very full notes on their geological origin, their agricultural value and importance, and to a lesser degree upon the botanical character of the natural growth. Some of these samples have been quite fully described in the Fourth Annual Report of the Maryland Agricultural Experiment Station, but only such peculiarities will be mentioned here as may seem necessary or desirable in the presentation of the results.

SOUTH CAROLINA SOILS.

Some very interesting conditions were presented in the study of the South Carolina soils, which throw light on the subject under consideration, and which show very plainly the relation of the texture and of the physical properties and condition of the soil to the local distribution of crops.

The conditions most favorable to the production of cotton may be briefly stated as follows: From the time of planting, the temperature and rainfall gradually increase until about the middle of July or the first of August, when the plant has practically attained its growth and has laid up all the food material needed for a full crop. During this growing period an even temperature is desired, with a high temperature as the plant attains good size. Plenty of sunshine is needed, and frequent rather than long continued showers. The ground is thoroughly cultivated and the crop is kept free of weeds and grass to conserve the moisture in the soil. The conditions which prevail are nearly tropical, and if they continued the plant would continue to grow as a perennial shrub with little tendency to ripen fruit. But after the first of August the temperature rapidly falls, there is less rainfall, cultivation is stopped, and the soil becomes cooler and drier, the real growth of the plant is checked, and the food material stored up by the plant is transferred to the fruit, and the plant ripens up a crop.

The *lower pine belt* in South Carolina covers nearly one-third of the state, but produces only about 5 per cent. of the cotton crop of the state, The soils are fair and the meteorological conditions must be favorable, for on one side of this belt are the fertile Sea Island cotton soils along the coast; on the other side is the fertile "red hill" formation, which contains some of the finest upland cotton lands of the state. The land in this lower pine belt is everywhere very level and very low, so that there is poor drainage, the water often rising to within a foot of the surface in the wells, and, indeed, covering much of the country between the water courses, as it can neither flow off the level surface nor down through the already saturated subsoil.

On what are called the "ridge-lands," bordering the water courses, and for two or three miles inland from the principal rivers, which have worn their way down in the soft material for 50 or 100 feet, the soils have good drainage, and very large crops of cotton are produced, while further away from the water courses the land is almost entirely left out in forest growth. Probably much could be done with this land with improved methods of cultivation and by judicious manuring, but the land needs underdrainage, and it would be both difficult and expensive to get good drainage in this low, flat country. Where cotton is cultivated there are all the signs of too moist a soil. The plant attains a large size, and one would suppose it would supply a large yield, but it puts on little fruit, hardly more than a third of what would be expected from the size of the plant, and much of this is lost by rust and shedding. The growth of the plant is not properly checked, and when a change does come it is sudden and severe, and lowers the vitality of the plant, rendering it liable to disease and insect ravages.

The texture of these soils and the relation to moisture undoubtedly determine the low yield of crop. The most important thing which could be done in the improvement of these lands would be the introduction of a system of under-drains, but even without this it would undoubtedly be possible to introduce improved methods of cultivation and manuring which would check this excessive growth, and induce the plant to ripen up a larger crop.

THE SEA ISLAND SOILS.

Very interesting conditions, showing the influence of soil moisture on the local distribution of crops, are seen on the Sea Islands off the coast of South Carolina. The soils of the Sea Islands consist generally of a very fine sand, the particles of which are of very uniform size, as shown by the mechanical analysis. The soils are naturally rather poor but are capable of a high state of cultivation. The natural growth is oak, hickory, gum, and chinquapin. There is no original pine, but fields left out grow up in old field pine. James Island, just across from Charleston, and one of the most northern of the the Sea Islands, and to which these notes have more particular reference, is some 8 or 9 miles long and from 2 to 3 miles broad. The soil on the south side is generally "sandy," with a sandy subsoil down to water level, which is from 5 to 6 feet below the surface. On the north side of the island or that nearest to the mainland, there is a yellow clay or loam subsoil. The surface of the water in the wells is generally 5 or 6 feet below the surface of the ground, and is quite fresh even if the well is near the shore. If the well is much deeper than this, however, the water is salt, even in the center of the island. This is in accordance with a statement made by Storer of conditions prevailing near Boston.

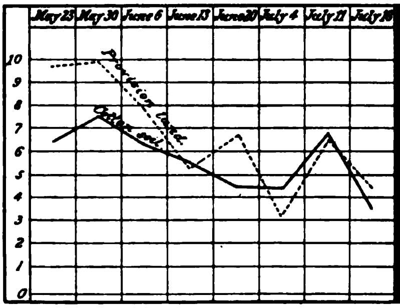
When the Sea Island cotton was first introduced into South Carolina, about 100 years ago, it failed to mature before frost, and for this reason the first crop was lost. The crop ripens now very much earlier so that there is no danger from frost. The planters have evolved a very peculiar system of cultivation, the plants are grown on very high beds or ridges from 12 to 18 inches high, and from 4 to 5 feet broad, partaking somewhat of the nature of the ridges used by the Romans, and for the same reason, *i. e.*, to keep the roots of the plant in thoroughly drained and comparatively dry soil. The subsoil is never disturbed and soft mud from the adjacent marshes and salt marsh grass and litter of all kinds are placed in the bottom of the bed, effectually keeping the roots from developing down into the moist subsoil. The bed itself is very highly manured. During the last twenty years the finest cotton lands have been gradually underdrained with tile drains, costing from $10 to $60 per acre, depending on the character of the land and the distance apart of the tiles. The sandy lands have only to be drained in low places, while in the heavier soils drains are placed from 25 to 100 feet apart and from 2 to 4 feet deep, with a fall of about 5 inches in 100 feet where possible. The planters believe that underdrainage has made the crop much earlier and surer and that the high beds are not now as necessary as formerly. They are able to maintain any grade of cotton desired by judicious cultivation and careful selection of seed.

The finest cotton lands are near the water, where the lands are better drained than in the interior. These lands are given up entirely to Sea Island cotton, and of recent years to early truck and vegetables for northern markets. The land in the interior of the island is not so well drained and does not yield as productive crops of cotton, nor as fine staple, as the crop is generally more liable to shedding, flagging, rust, and insect ravages than on the better drained soils just described; this land is better for corn than the finest cotton soils, and it is generally known as "corn" or "provision land," as it is given up to the cultivation of corn and provisions for the farm.

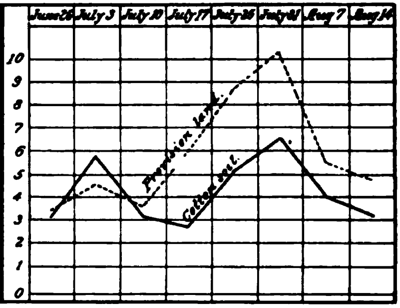
Cotton usually starts out well on this land and the plants attain a large size but put on very little fruit and are liable to disease and insect ravages.

The following diagrams show the moisture curve in two soils from James Island, S. C. Both soils were in cotton and samples of the

James Island, S. C., soils, 1890.



James Island, S. C., soils, 1891.



soil were taken weekly for the moisture determination. The sample was taken with an iron tube 9 inches long and 2 inches in diameter, which was driven down its whole length into the soil. The sample was sent to the station in air-tight glass jars, and the moisture was determined by air-drying about 1,000 grams of the material.

The time covered only a part of the growing period of the crop each year. In 1890 this was of the early part of the season, and in 1891 of the middle and latter part of the true growing season before the ripening period really commenced.

It will be seen that the moisture curve for the provision land is very much more irregular than that for the cotton soil, and it is undoubtedly these marked and sudden changes which render the crop less certain. On July 25, 1891, rust appeared in the cotton on the provision land, and by September 4th the plants had lost nearly all their leaves from this cause.

The planters themselves believe that underdrainage and high beds, with heavy applications of salt mud to keep the roots from developing down into the subsoil, will check the growth of the plant and enable as good crops to be grown here as elsewhere, but as these lands are inland, both the mud and drainage are costly and difficult to apply.

The mechanical analyses of some of the soils from James Island are given in the accompanying table, including three principal types of Sea Island cotton lands and one sample of the "provision" land from the interior, on which cotton cannot be economically produced. The approximate extent of surface area, in square centimeters per gram, and the approximate number of grains per gram, are also given as calculated by the formulæ already given. The results cannot be compared directly with the work on the Maryland soils for there are not so many separations, and the absolute values are not the same.

Mechanical analyses of Sea Island cotton subsoils from James Island, S. C.

Diameter.	Conventional names.	Sea Island cotton lands.			
		82.	84.	86.	88.
		Clay land.	"Sand and gravel."	Sandy land.	Provision land.
mm.					
2–1	Fine gravel	0.00	0.59	0.00	0.00
1–.5	Coarse sand	0.54	3.67	0.00	0.88
.5–.25	Medium sand	1.03	4.27	0.67	2.50
.25–.05	Fine sand*	83.20	78.88	90.14	82.97
.05–.01	Silt	6.44	4.20	3.35	6.30
.01–0	Clay†	7.17	6.63	4.78	5.70
	Total	98.38	98.24	98.94	98.35
Organic matter, water, loss		1.62	1.76	1.06	1.65

Mechanical analyses—Continued.

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
86	Sandy land	4.78	383.7	279,000,000
88	Provision land	5.70	441.9	336,000,000
84	Sand and gravel	6.63	464.8	390,000,000
82	Clay land	7.17	509.7	421,000,000

* Including "very fine sand" of later analyses (.1–.05 millimeter).

† Including "fine silt" of later analyses (.01–.005 millimeter).

The "provision" land need hardly be considered here, for the trouble with the land is admitted to be poor drainage, owing to its location; and in many cases it has a layer of iron ore underlying it at a depth of 3 or 4 feet from the surface.

Of the cotton soils the clay land (82) is considered the strongest soil. With the same treatment it produces a larger yield per acre, although the fiber is rather shorter and heavier, than the sandy land. The Sea Island planters have an admirable method of selecting seed and they can maintain almost any desired grade of lint. They select the sandy land (86), however, in preference to the clay land for the finest grade of lint. With the same seed and treatment the sandy land does not produce so much yield per acre as the heavier clay land; the plants moreover are not so large, the crop ripens earlier, and the lint is somewhat finer and longer. The agricultural value of these cotton soils varies with the amount of clay they contain and with the approximate number of grains per gram, as given in the table, and the planters realize that the sandy soils are less retentive of moisture and are, as a rule, drier, and that it is this fact, rather than lack of plant food, which explains the difference in their agricultural value.

THE WEDGEFIELD SOILS.

Very interesting conditions have also been studied in three soils from Wedgefield, S. C. Wedgefield is situated on a narrow strip of the "red hill" formation, about 2 miles from the Wateree River, and the railroad station is about 150 feet above low water, with a bold bluff coming down to the swamp, about half way between the station and the river. The soil of this red hill formation has a strong, dark red clay-loam subsoil. The formation widens out considerably in Orangeburgh and Aiken counties, and is noted throughout its whole extent for its fertility and the excellent conditions for a good cotton soil. The land is gently undulating, with good surface drainage, and, although a compact red clay from 40 to 80 feet thick, it has good underdrainage. It is considered a very safe soil, as cotton rarely suffers from excessive wet or dry weather and the plants are usually very vigorous and are not subject to rust, shedding, or lice, as on the adjacent lands. With good treatment it may be relied on to produce 1,000 to 1,400 pounds of seed cotton. If anything, the soil is considered rather too close and too retentive of moisture, and this, together with rather high nitrogenous manuring, has inclined the plant on this particular soil to make rather an excessive growth for the amount of fruit which it produces. On the whole, the soil of this formation is considered the finest type of upland cotton soil in the state. The wells are usually about 40 feet deep, but are often 80 feet and even 120 to 160 feet deep.

About 1¾ miles from the station at Wedgefield, there is a range of sand hills bordering the red hill formation and extending for miles up and down the river. The soil and subsoil are coarse, yellow sand, with red clay fully 15 to 20 feet below the surface, on the plateau where these samples were taken just before entering the sand hills proper. Cotton cannot be economically produced on this land, for the soil is so light in texture that the crop suffers in excessive wet or dry weather. With the same treatment it is thought that it will not make one-fifth as much cotton per acre as the "red land." The sandy land makes fairly good crops of corn and is excellent for sweet potatoes, melons, and early truck. It is never planted in cotton by the large planters.

There is a narrow belt, about ½ mile wide at this place, lying between the red hill formation and the sand hills, locally known as "gummy land," because, although it appears to be a coarse, red sand, it gums up and sticks to a plow, especially when it is quite moist. In color it is precisely like the red land, and the mechanical analysis shows that it contains about the same amount of clay. In texture it looks and feels like red sand. In its relation to moisture, also, it behaves more as a sand than as a clay, so that crops suffer in excessive wet or dry seasons. In unfavorable seasons the plants are small and the vitality of the plants is so much lowered that they are rendered liable to disease and insect ravages. In a good season and with the same manuring and treatment it is thought that this land will make only about four-fifths as much crop as the red land, but in unfavorable seasons the difference is much greater than this.

No amount of fertilizers, as usually applied, will make these two soils as productive or as safe for cotton as the red land. The meteorological conditions are the same over all, and the difference is undoubtedly due to the physical properties of the soils, and especially their relation to water, rather than to any difference in chemical composition. The planters themselves freely admit that the peculiarity of these soils and their natural or acquired fertility are largely dependent on their relation to the moisture supply of crops.

The mechanical analyses of these soils are given in the accompanying table, with the approximate number of grains per gram and the approximate extent of surface area of these grains in square centimeters per gram.

Mechanical analyses of subsoils from Wedgefield, S. C.

Diameter.	Conventional names.	74.	76.	78.
		Red land.	"Gummy" land.	Sandy land.
mm.				
2–1	Fine gravel	1·11	1·98	2·88
1–·5	Coarse sand	5·92	14·91	31·45
·5–·25	Medium sand	9·67	20·17	27·31
·25–·05	Fine sand*	42·75	25·47	28·14
·05–·01	Silt	7·54	6·92	3·96
·01–0	Clay†	28·85	26·25	3·97
	Total	95·84	95·70	98·68
Organic matter, water, loss		4·16	4·30	1·32

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
78	Sandy land	3·97	284·8	232,700,000
76	Gummy land	26·25	1,358·0	1,567,000,000
74	Red land	28·85	1,496·0	1,736,000,000

* Including "very fine sand" of later analyses (.1–.05 millimeter).

† Including "fine silt" of later analyses (.01–.005 millimeter).

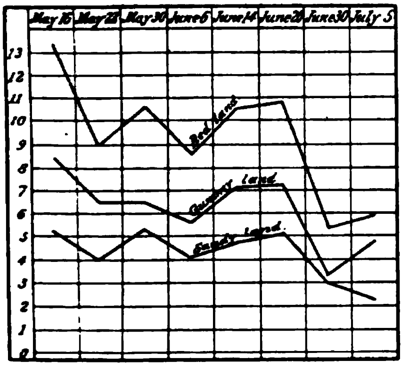
The amount of empty space in these lands is given in a preceding table, and it will be seen from this table that this space is divided more in the red land than in the sandy land, as there are a great many more grains in the former than in the latter. Experiments were tried with the air-dried soils in the laboratory to determine the relation of these soils to water and especially the ease with which water would move through them.

A quantity of the red land was loaded into a tube, the amount of space being determined in the way already described. An inch in depth of water (41 cubic centimeters) passed through the saturated subsoil in 133 minutes. As this soil is considered rather close and retentive of moisture, making the crop rather late in starting off and growing rather late in the fall, a number of fertilizing materials were applied to diminish the rate of flow. A few drops of a saturated solution of gypsum made the water pass in 105 minutes, as a result of several trials.

Taking 133 minutes for the red land as a basis of calculation, the same quantity of water should pass through the same depth of sandy land of a given compactness and as calculated from the mechanical analysis in 5½ minutes. The water actually passed through in 3¾ minutes, a result agreeing very closely with the calculated time. The "gummy land" contains very nearly as much clay and very nearly as many grains per gram as the red land, and it was calculated from the mechanical analysis that the same quantity of water should pass through this subsoil, as loaded in the tube, in 130 minutes. The water actually passed through in 14 and 16 minutes, as a result of several trials. The soil appears like a sandy soil. The mechanical analysis shows that it contains only about the same amount of the different grades of sand as the red land, but it has rather more of the coarser grades. It appears as though the clay were held closely to the grains of sand, through flocculation perhaps, giving the appearance of larger grains than the soil really contains. In the mechanical analysis of the material flocculation was so troublesome that ammonia had to be used to overcome and prevent it, as the clay liquid would settle out clearly and at once without this addition. A few drops of ammonia were, therefore, added to the water as it was passing through the subsoil in the tube, and it checked the rate of flow *at once*, so that it took over 2,000 minutes for the liquid to pass. The alkali was evidently stronger than it should have been, as it made the soil almost impervious to water. The action of the alkali on the soil could be traced as it proceeded down the tube, the soil appearing to slake and the grains of clay to fall away from the grains of sand. The action could be distinctly watched through a microscope focused against the inside of the tube. The fine silt and clay particles could be seen to leave the grains of sand and gather in loose light flocks in the spaces within the soil.

There seems no doubt but that the trouble with this soil was in the arrangement of the soil grains, in which the clay particles did not have their best effect in retarding the rate of flow and in making the soil sufficiently retentive of moisture. The grains were probably so arranged that some of the spaces within the soil were relatively extremely large. The ammonia changed this and caused a rearrangement of the soil grains by which they were more evenly distributed throughout the soil. It is probable that other substances would have had the same effect, and that through their judicious use the grains of clay could have been pushed a little further apart, and the soil be made as retentive of moisture as the red land and as productive and as safe a soil for cotton. This is the line in which the improvement of this land should be worked out. There is sufficient clay in the land to make it as retentive of moisture as is required in the best cotton soil, and to improve the land the object should be to push these grains of clay apart so as to change the texture of the soil.

Diagram showing the percentage of moisture in the Wedgefield soils.



Samples were taken from each of these three soils once a week during a portion of the season of 1890, and moisture determinations were made by air-drying the soils. The samples were taken to a depth of 9 inches from the surface. The preceding diagram shows the amount of moisture in the soils at the stated times.

It is to be observed that the season, as a whole, was too wet for the best development of the crop. On the red land this resulted in rather too much growth and too little fruit in proportion to the size of the plants, but the plants themselves were otherwise vigorous and healthy. On the "gummy land" and sandy land, however, the vitality of the plants was seriously impaired by the frequent and heavy rainstorms; the plants were small and were very seriously injured by lice. It happened that the rain came in very heavy and soaking storms, almost invariably three or four days before the samples were taken, and this was followed by a succession of hot, sunny days, so that the diagram does not give a true idea of the moisture in the soils, as it would if the rainfall had been more evenly distributed, or if the samples had been taken at more frequent intervals. The difference in the moisture content of these soils, as shown by the diagram, is probably amply sufficient to account for the difference in the agricultural value of the lands. When it is considered, also, that this was an unusually wet season, the amount of moisture which can be maintained for the crop by the sandy land in an average season must be very small. It is unfortunate that these records could only be extended over part of a single season.

One cannot help but think that the difference in the agricultural value of these three soils is due to the relation of the soils to water, and the amount of water which they can maintain for the crops, and that this factor, alone, determines the local distribution of crops and makes it evident why melons and sweet potatoes are admirably adapted to the "light lands," and cotton to the heavy clay or loam soils.

If it is conceded that this is the trouble with the "gummy land" it will be comparatively a simple matter to work out methods of treatment or fertilization which will overcome this trouble. It would be much easier to improve the land in this direction and to force the grains further apart than it would be to draw the grains more closely together in the impervious Potomac clays of Maryland, and make them more loamy and less retentive of moisture. It must be recognized, however, that this physical condition of the soil is the controlling cause in crop production and that any fertilization is not, or should not be, primarily, to supply plant food to the soil but to act in changing the physical structure of the land. The "best fertilizer" for this land may have little or no commercial value, or it may be any one of the high grade commercial fertilizers.

Many other interesting problems, showing the effect of the texture of the soil and the relation to water on the distribution of crops, could be given as presented by the South Carolina soils and in the cultivation of the cotton crop. Cotton is as sensitive to these conditions of heat and moisture as many greenhouse plants, and responds readily and quickly to changes in these conditions. If the season or soil is too wet, the plants are inclined to excessive growth and put on but little fruit; if too dry, the plants do not attain sufficient size but put on generally more fruit in proportion to the size of the plant and the amount of food material which has been stored up. Sudden changes of moisture or temperature lower the vitality of the plant and render it liable to disease and insect ravages. The plant is peculiarly sensitive to these physical conditions and is admirably adapted to these soil investigations.

It is to be regretted that this work could not have continued in South Carolina as the point had just been reached where a large amount of material and data had been collected to work with, but the work was, unfortunately, broken up.

MARYLAND SOILS.

We come now to speak of some problems presented by the soils of Maryland, where, it will be understood, much time has been spent in necessary preliminary work in collecting material and data. We have also to leave the study of cotton, which is so extremely sensitive to its environments, and take up the study of wheat, which is not very sensitive but which, on the contrary, readily adapts itself to marked changes in its environments, as seen in the very wide and general distribution of the plant throughout the world.

The average yield of wheat per acre for each county in Maryland, as calculated from the returns of the tenth census, is as follows:

Average yield of wheat per acre, as given in the tenth census.

	Bushels.
Southern Maryland:	
Charles	7. 1
Calvert	7. 6
Saint Marys	8. 3
Anne Arundel	9. 0
Prince George	9. 0
Average	8. 2
Eastern Shore:	
Worcester	7. 1
Wicomico	7. 2
Dorchester	7. 6
Caroline	10. 2
Somerset	10. 3
Queen Anne	13. 5
Talbott	14. 1
Kent	14. 8
Average	10. 6

Average yield of wheat per acre—Continued.

Northern and Western Maryland:	
Allegany	8.9
Garrett	10.7
Baltimore	13.7
Carroll	14.4
Cecil	15.7
Howard	16.5
Harford	16.7
Montgomery	16.9
Frederick	16.9
Washington	18.0
Average	14.8

The state of Maryland contains approximately 10,000 square miles of land surface. It is divided geographically into four sections: Southern Maryland, having an area of approximately 2,000 square miles, has gently rolling country, and forms a peninsula with the Chesapeake Bay on the east and the Potomac River on the south and west. The Eastern Shore, containing approximately 3,000 square miles with generally level surface, having the Chesapeake Bay on the west, the Atlantic Ocean and the state of Delaware on the east, and two counties in Virginia on the south. Northern and western Maryland contain together approximately 5,000 square miles, and may be classed together here for the following study. The surface is quite rolling in northern Maryland and mountainous in western Maryland.

The largest average yield of wheat per acre, as given in the above table, is 18 bushels in Washington county. This is principally from the heavy clay lands of the Trenton chazy limestone formation of the Cumberland Valley. The lowest average yield per acre is in the lower counties on the Eastern Shore and southern Maryland. The soil on the lower part of both of these peninsulas is notoriously light and sandy. The Eastern Shore and southern Maryland belong to the Coastal Plain, and have the undisturbed and unconsolidated strata from the Jurassic to the present time. Northern-central Maryland belongs to the Piedmont Plateau, made up of the highly crystalline rocks towards the east, and semi-crystalline towards the west. Western Maryland contains the entire sequence of Paleozoic strata, in several series of folds or undulations. The geology of the Eastern Shore has not yet been worked out in any detail, and there has been no attempt to examine or classify the soils.

The soils of southern Maryland are generally light in character and texture, ranging in texture from the very light sands of the Lafayette and Columbia terrace formations, containing as little as 4 per cent. of clay in the subsoil, to the heavier lands of the Neocene formation, containing as much as 25 or 30 per cent. of clay.

The soils of northern and western Maryland have, as a rule, not less than 25 or 30 per cent. of clay, and the finest grass and wheat lands in the limestone formations have as much as 40 or 50 per cent of clay. The soils of southern Maryland are, as a rule, distinctly lighter in texture than those of northern and western Maryland, and this undoubtedly explains the low average yield of wheat in this locality, as given in the table. This is clearly recognized by practical men acquainted with the two localities. They can not judge of the difference in the chemical composition of the soil; the area of the state is so small that there can not be great differences in climatic conditions, but they will say, from the general appearance of the land, that it is not as "heavy" as the finer wheat lands of western Maryland. It is not a matter of mere plant food; it is not because the preparation and cultivation in these Eastern Shore and southern counties are less thorough, but the land itself is too "light" to maintain a larger yield of grain or a permanent sod of grass.

It is quite possible in water or sand-culture, where the conditions of moisture, temperature, and aëreation can be perfectly controlled, to add sufficient plant food to the otherwise sterile medium for the production of a normal crop. If the conditions of moisture and temperature in the light, sandy truck lands or of the pine barrens of southern Maryland are favorable for the production of wheat, then it should be possible, as in sand-culture, to produce a crop of wheat, if sufficient plant food be added to the soil. But no one would suppose for a moment that the mere addition of plant food would enable a good wheat crop to be produced on this light, sandy land. It can not be economically produced on them under existing climatic conditions, unless vast quantities of organic matter were added to the land to change the whole character and texture of the soil and make it more retentive of moisture. If the soil cannot maintain a sufficient supply of water for the crop, then this becomes a controlling factor and limits crop production. We will show that these light lands of southern Maryland are not as retentive of moisture as the heavier wheat and grass lands of northern and western Maryland, and that this follows from the lighter texture of these soils, from which the practical farmer judges of the agricultural value of the land and the kind of crop which can be economically produced. It appears, therefore, that the controlling cause in the production of crops and in the local distribution of crops in these different soil formations in the state is largely due to the texture and general physical conditions of the soil, especially to their relation to water and the amount of water which they can maintain for the crop under existing climatic conditions.

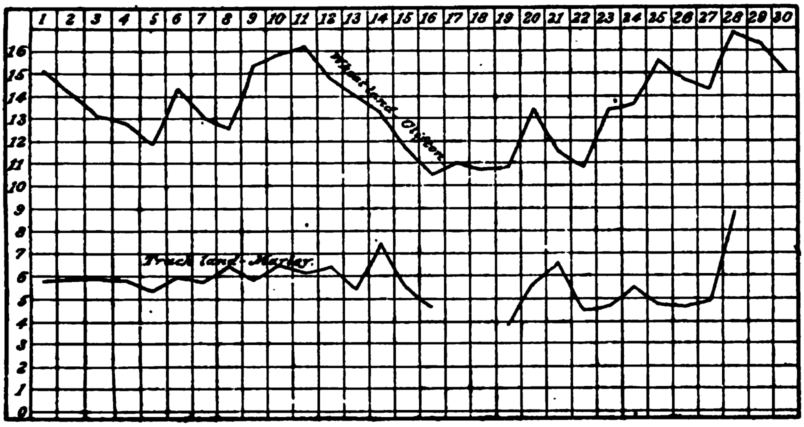
A number of stations have been established in several of the principal soil formations of the state for the study of the moisture and temperature of the soil. The soils of the different formations have markedly different texture and are widely different in their agricultural value. The stations are near volunteer observing stations of the Weather Bureau, or have the ordinary meteorological instruments supplied: They are not yet fully equipped, but are to have in addition to the above instruments a soil thermometer of a special construction, with a bulb 6 inches long, extending from 3 to 9 inches below the surface. It has a straight stem inclosed in a wooden case, as in the ordinary soil thermometer, but with maximum and minimum indices in the tube to register the highest and lowest temperature. The bulb has a special construction, devised by Professor Marvin of the Weather Bureau, to allow of the use of the two indices in the same stem. If the instrument is as successful as it gives promise of being it will be fully described at another time.

Moisture determinations are to be made in samples of the soil at the different stations, taken in small brass sampling tubes, $\frac{3}{4}$ of an inch in diameter and 9 inches long, with a mark on the side of the tube 6 inches from one end, which is the depth to which the sample is taken. Rubber caps are slipped over the open ends of the tube and it is put into a small bag and sent by mail. The moisture is determined by drying 50 grams of the sample in a porcelain dish in a water bath for five hours. The sample represents the first 6 inches in depth from the surface down. It would be well if the sample could be taken at a uniform depth of from 3 to 9 inches, or from 6 to 12 inches below the surface, but this is impracticable at these volunteer stations. It was decided that it would be impossible to secure uniform conditions if the soil were under cultivation or if any plants were allowed to grow on them, so that a small plot of land, at least 10 feet square, is reserved for this work. It is to remain undisturbed during the season, except that grass and weeds are to be removed by hand.

A convenient method is much to be desired for the determination of moisture in the soil without disturbing the natural position of the soil or removing or changing the instrument in any way. Various methods have been suggested and a number of the most promising methods were tried by Sturtevant, at Geneva, but none of them have been perfected. The writer has been trying to work out a method based on the change of electrical resistance of the soil with the changing moisture content. It is impossible, however, to get perfect contact with the soil and the plates, and it seems that this method can not be perfected. The method itself and the difficulties will be more fully discussed in another part of this report.

These moisture observations have not been continued sufficiently long to provide data for this report, but a single diagram is given showing the moisture in the soil in an open bed in the lawn at Clifton, where this work is located, and in the light, early truck lands at Marley.

Diagram showing the percentage of moisture in the wheat and truck lands.



The soil at Clifton is a fairly good wheat land, apparently about as strong as the better class of wheat lands of southern Maryland, although it belongs to an entirely different geological formation. The soil from Marley represents the very light, early truck lands between Baltimore and Annapolis, which will be described in some detail in another part of this report. These samples were taken by Mr. T. W. Soley, of Marley, and sent by mail for the moisture determinations. Neither of the soils were cultivated nor disturbed in any way during this period.

The mechanical analysis has not been made of the soil at Clifton for the reason that the whole of the Potomac formation, to which it belongs, is extremely uneven. The moisture determinations, however, agree very closely with the moisture in samples from the Neocene wheat land at South River, which contains 17.87 per cent. of clay. The truck land from Marley has only 4.40 per cent. of clay.

The difference in the amount of moisture maintained by these two soils, as shown by the diagram, is probably amply sufficient to account for this local distribution of crops. Grass and wheat cannot be economically produced on a soil which can maintain much less water than that at Clifton, and certainly not in a soil which can only maintain as little as that at Marley.

These two localities are not over 8 or 10 miles apart in an air line, and the meteorological conditions could not have been very different. The "season" was very favorable at each place, the rainfall being rather more than the normal at both places. With the climatic conditions sensibly constant, we see here that these two soils maintain very different conditions of moisture for crops. Rain does the crop little or no good until it enters the soil. We see that one of these soils lets the rainfall pass through it readily and maintains not more than one-half or one-third as much moisture for the use of the crop as the other. Each of these conditions, if artificially maintained in a greenhouse, would be distinctly favorable to some kinds of plants and unfavorable for the proper development of others. As stated before, if the conditions in this wheat soil at Clifton are normal and necessary conditions for the growth of wheat, which can not be doubted, then this inability of the light truck land to maintain a more abundant water supply, while distinctly favorable to the early ripening of truck, is a controlling factor in the economical production of wheat, and this relation of the soil to moisture becomes as potent a factor as a controlling cause in the local distribution of crops as temperature is in the general distribution of plants.

In the arrangement and classification of the samples of soil which have been obtained in Maryland, it appears that the staple crops are distributed according to the amount of clay and the approximate number of grains per gram contained in the subsoil, if the subsoil is of sufficient depth to regulate the drainage and to give character to the land, and if the grains can be assumed to have a mean symmetrical arrangement, as in most of our great soil formations. It appears that our staple crops are distributed according to the following percentage of clay in the subsoil, which, as has been shown, largely determines the texture of the soil and the relation of the soil to moisture: Barrens, less than 4 per cent.; early truck, 4–10 per cent.; tobacco, 14–18 per cent.; wheat, 18–50 per cent.; grass, 25–50 per cent. This applies of course only to the meteorological conditions which prevail in this State and when the grains are assumed to have the same symmetrical arrangement.

THE EARLY TRUCK LANDS OF SOUTHERN MARYLAND.

There is a narrow strip of coarse, sandy soils bordering the Chesapeake Bay from Baltimore down to South River, entirely devoted to the production of early truck and vegetables for the Baltimore and the larger northern markets. This same character of soil is found along the coast as far south as Florida, and on all of it truck is raised, but it is only of the small area between Baltimore and Annapolis that these remarks have special reference.

The coarse, sandy soils and subsoils of the early truck lands between Baltimore and Annapolis contain from 4 to 10 per cent. of clay. Other things being equal, the lighter the soil and the less clay it contains the earlier the crop. Soils having over 7 per cent. of clay are rather heavy for the earliest truck, but are well suited to tomatoes, cabbages, small fruits, and peaches. Geologically these light soils belong to the Columbia terrace formation, although there are good truck lands in this area on the Eocene soils which contain not over 8 or 10 per cent of clay and are excellent for peaches and the heavier truck. A large part of this area is lying out as a barren and unproductive waste for lack of proper facilities for transportation. This matter of cheap and quick transportation is so great a factor in the trucking interest, owing to the bulky and perishable nature of the market truck and small fruits, that lands directly on the water courses have a value many times greater than similar lands situated only a mile or two from the river.

Peas, tomatoes, cabbage, sweet potatoes, watermelons, canteloupes, strawberries, raspberries, and peaches may be grown, and are grown, with more or less success on nearly all kinds of soil. But this area of coarse, sandy land in southern Maryland will produce these crops at least a week or ten days earlier than the far heavier wheat and grass lands in other parts of the state. This puts the truck into the Baltimore and northern markets much earlier than it can be produced on the heavier soils of the state, and insures the early truck farmers from competition from the state at large, and they get very fair prices, as their crops are sold before the market prices fall with the glut of summer vegetables. It requires a very heavy outlay for manuring and for labor in the trucking business, and everything depends upon their getting their crop to market at the earliest possible date to take advantage of the high prices, and no pains or expense is spared to force the maturity of the plant and hasten the ripening of the crop.

The early truck lands are much too light for the profitable production of wheat or corn, or of any of the staple crops whose period of growth extends into or through the summer months, not because the soils are deficient in plant food, but because the soils are so coarse and open in texture that they are unable to maintain a sufficient water supply for these crops during the hot spells which are liable to occur. It is not that these light, sandy lands produce as much yield per acre of the different kinds of market truck as the heavier lands that they are utilized for trucking, but that they ripen the crops earlier and so get advantage of the higher prices. There are, therefore, peculiar conditions desired in an early truck land, just the opposite conditions, indeed, from those required for a good grass or wheat soil. The soil, or rather subsoil, of the truck lands should be very light in texture, containing not over 10 per cent. of clay, and for the very earliest truck not over 6 per cent. If they have more than this, the soil is too retentive of moisture, and the growing period is prolonged and the ripening of the crop is delayed. In the truck land with less than 6 per cent of clay, the soil is drier and probably cooler, and these are conditions which would hasten the maturity of the crop.

Other things being equal, the more clay a soil contains the more retentive of moisture it will be, and the greater the amount of moisture which would be maintained in the soil for the crop. The fine particles of clay not only make the spaces within the soil exceedingly small, so that the rainfall must pass downward very slowly through the soil, but by increasing the area of the water-surface it increases the power the soil has of drawing water to the plant to supply the loss from evaporation and to replace that which has been used by the plant. In a heavy clay soil this supply of water may be so abundant as to prolong the growth of the plant and increase the size and yield per acre, but may greatly retard the ripening of the crop.

The average yield of wheat in Washington county is given by the census as 18 bushels per acre, and this is principally from a limestone soil having over 40 per cent. of clay. Wheat can not be economically produced on the light truck lands. It is not that the soils of Washington county contain necessarily more plant food than the truck lands of southern Maryland, but that having more clay the soils are stiffer and more retentive of moisture, and they can maintain a more abundant supply of water for the crop.

These limestone soils are too retentive of moisture for early truck. In an average season they would maintain such an abundant supply of water that, although large crops would be assured, the crops would be late in coming to maturity, and would come into competition with crops from all parts of the state. The light character of the land, therefore, gives the early truck planter a monopoly of the market.

The mechanical analyses of the subsoils from a number of localities will be given, with the surface area and the approximate number of grains per gram, with such notes as may be necessary on the agricultural value of these lands.

Mechanical analyses of truck subsoils from southern Maryland.

MARLEY NECK.

Diameter.	Conventional names.	471.	472.	591.	469.	473.	590.
		Marley P. O.	Marley P. O.	1 mile north of Marley P. O.	Glenburnie.	Albert Hammond.	2 miles north of Marley P. O.
mm.							
2–1	Fine gravel	0.28	0.49	0.39	3.47	0.44	0.91
1–.5	Coarse sand	5.42	4.96	5.52	12.05	6.46	5.45
.5–.25	Medium sand	41.45	40.19	36.53	44.06	36.73	28.73
.25–.1	Fine sand	26.73	27.59	24.91	18.02	19.54	22.81
.1–.05	Very fine sand	12.46	12.10	11.79	9.59	10.28	13.44
.05–.01	Silt	7.22	7.74	9.89	5.73	13.42	14.77
.01–.005	Fine silt	2.21	2.23	4.51	1.37	5.61	4.29
.005–.0001	Clay	4.07	4.40	5.41	5.46	7.14	9.16
	Total	99.84	99.70	98.95	99.75	99.62	99.56
Organic matter, water, loss		0.16	0.30	1.05	0.25	0.38	0.44

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
471	Marley P. O	4.07	583	1,809,000,000
472	......do	4.40	615	1,955,000,000
591	1 mile north of Marley P. O	5.41	796	2,458,000,000
469	Glenburnie	5.46	654	2,406,000,000
473	Albert Hammond	7.14	987	3,215,000,000
590	2 miles north of Marley P. O	9.16	1,173	4,078,000,000

Mechanical analyses of truck subsoils from southern Maryland.

TICK NECK.

Diameter.	Conventional names.	585.	583.	587.
		Sandy land.	1½ miles northeast of Armigers.	Loam.
mm.				
2-1	Fine gravel	0.45	0.28	6.06
1-.5	Coarse sand	10.33	6.09	22.09
.5-.25	Medium sand	46.29	39.48	29.87
.25-.1	Fine sand	20.15	23.00	9.82
.1-.05	Very fine sand	8.17	14.69	6.52
.05-.01	Silt	7.11	8.46	10.71
.01-.005	Fine silt	2.29	2.48	3.86
.005-.0001	Clay	4.77	5.01	7.89
	Total	99.76	99.45	96.82
Organic matter, water, loss		0.24	0.55	3.18

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
585	Sandy land	4.77	629	2,121,000,000
583	1½ miles northeast of Armigers	5.01	673	2,185,000,000
587	Loam	7.89	987	3,621,000,000

The soils from Marley Neck, having less than 6 per cent. of clay, as shown by the table, are considered very typical early truck lands. 473 is from a ridge of rather heavier land, having 7.14 per cent. of clay. The land where this sample was taken is considered rather heavy for the very early truck, but is excellent land for small fruits. The same may be said of 590, although less is known of this sample.

On Tick Neck, also, we find that the very earliest truck lands have less than 6 per cent. of clay. The sample of loam, 587, was taken far down on the point, in what is considered the garden spot of the truck area. There is a narrow strip of this loam soil extending along the bay shore and covering the points of these river necks. This strip is from one-half a mile to a mile wide, and contains considerable gravel in the subsoil about 2 feet below the surface. There are only small areas of the lighter sandy land containing less than 6 per cent. of clay. By reason of the location on the bay shore, with rivers and creeks making up in all directions into the farms, the climatic conditions are peculiarly mild and the truck planters are insured against frost. They can plant earlier so that these loam soils are as early, or earlier, than the light lands further up the river necks, represented by the other two samples in the table, although it is recognized by the truck planters that the period of growth is somewhat longer, and under exactly the same climatic conditions the crops would be later in coming to maturity on this loam soil than on the lighter sandy lands. It is, of course, a distinct advantage, however, to have both the heavier soil, which will produce more crop per acre, and the favorable situation nearly surrounded by water to insure against frost and to allow the crops to be planted earlier.

Mechanical analyses of truck subsoils from southern Maryland.

ROCK POINT.

Diameter.	Conventional names.	579.	581.
		Jas. Meek.	¼ mile north of McCubbins.
mm.			
2-1	Fine gravel	0.09	0.56
1-.5	Coarse sand	2.31	4.83
.5-.25	Medium sand	31.18	27.49
.25-.1	Fine sand	25.49	16.36
.1-.05	Very fine sand	16.92	12.51
.05-.01	Silt	12.86	22.39
.01-.005	Fine silt	3.82	5.03
.005-.0001	Clay	6.33	10.12
	Total	99.00	99.29
Organic matter, water, loss		1.00	0.71

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
579	James Meek	6.33	886	2,850,000,000
581	¼ mile north of McCubbins	10.12	1,348	4,471,000,000

The two samples from Rock Point contain rather more clay than from the other localities, but very little is known of the agricultural features of these soils. 581 came from a ridge, and would be regarded as a decidedly heavier soil than 579, and better suited to small fruit.

Mechanical analyses of truck subsoils from southern Maryland.

NORTH MAGOTHY NECK.

Diameter.	Conventional names.	561.	563.	565.	567.	577.	589.	575.	571.	569.	573.
		Armiger.	Armiger.	2 miles west of Armiger.	1 mile west of Armiger.	J. M. Cook.	2 miles north of Armiger.	J. M. Cook, loam.	Dr. E. Williams, loam.	Dr. E. Williams, loam.	J. M. Cook, gravelly loam.
mm.											
2-1	Fine gravel	0.74	0.39	2.12	2.46	1.52	2.33	1.26	0.34	0.87	3.67
1-.5	Coarse sand	7.13	7.04	8.81	13.32	4.50	26.08	8.91	2.97	5.82	11.92
.5-.25	Medium sand	36.21	37.51	31.35	39.83	29.88	33.06	47.84	21.18	26.22	29.99
.25-.1	Fine sand	22.82	21.45	22.82	14.14	23.77	10.18	6.29	18.19	17.55	6.35
.1-.05	Very fine sand	14.15	13.45	16.76	9.34	10.36	4.71	6.29	17.17	16.34	5.56
.05-.01	Silt	9.26	10.72	10.19	10.17	17.16	13.14	15.08	21.05	16.33	21.91
.01-.005	Fine silt	4.68	3.72	2.08	3.29	3.83	3.58	5.76	9.57	7.45	6.21
.005-.0001	Clay	4.71	5.41	5.47	6.36	8.01	8.29	8.33	8.39	8.52	12.84
	Total	99.70	99.69	99.50	98.91	99.03	102.39	99.92	98.86	99.10	98.45
Organic matter, water, loss		0.30	0.31	0.50	1.09	0.97	......	0.08	1.14	0.90	1.55

Mechanical analyses—Continued.

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
561	Armiger	4.71	727	2,137,000,000
563	......do	5.41	769	2,427,000,000
565	2 miles west of Armiger	5.47	721	2,429,900,000
567	1 mile west of Armiger	6.36	824	2,856,000,000
577	J. M. Cook	8.01	1,060	3,596,000,000
589	2 miles north of Armiger	8.29	961	3,587,000,000
575	J. M. Cook, loam	8.33	1,102	3,676,000,000
571	Dr. E. Williams, loam	8.39	1,296	3,862,000,000
569	......do	8.52	1,204	3,869,000,000
573	J. M. Cook, gravelly loam	12.84	1,562	5,779,000,000

Of the samples collected on North Magothy Neck, the first four are typical early truck lands. They are very coarse, sandy soils, and in their natural condition they are little more than barren wastes. Under the peculiar and intense conditions of manuring and cultivation, however, they are admirably adapted to early truck and they are classed as the very earliest truck lands of the locality. 569 and 571 are of a loam soil from a ridge, similar to the ridge on Marley Neck where sample 573 was secured. Off of this ridge and down near the Magothy River, but on the same farm, the light lands prevail, containing not over 5 per cent. of clay in the subsoil. Dr. Williams stated that these light lands were his earliest truck soils, and that tomatoes, for example, will ripen at least a week earlier on the light lands than on the loam soil. Tomatoes and cabbages do better and yield more per acre on the loam soil, but they are not so early and, consequently, do not bring as good prices as the crops from the lighter soils. Time is everything to the early truck planter, and these light lands have some peculiar property which adapts them to this early truck and matures the crop earlier than on any other soils of the state. The loam soils are much better adapted to small fruits and peaches than the very light lands.

At the extreme end of Magothy Neck there are the same loam soils referred to in speaking of the soils of Tick Neck, of which 573 is considered a representative sample from this locality. There is considerable gravel in the subsoil about 2 feet below the surface. 575 and 577 are from lighter lands on the upper part of the same farm. These lighter soils are earlier than the heavier loam, but, by reason of the locality right on the bay shore and with rivers and creeks making up into the farm in all directions, this loam soil (573) is considered earlier than the loam soils at Dr. Williams, and probably as early as the lighter truck lands at Armiger. It is considered excellent for peaches and for truck, as it produces more per acre than the light lands, and, by reason of the location near the bay shore, the crop can be planted earlier and so will mature earlier than on even lighter lands further up the river neck.

Mechanical analyses of truck subsoils from southern Maryland.

SOUTH PATAPSCO NECK.

Diameter.	Conventional names.	467.	476.
		Shipley.	Furnace Branch.
mm.			
2-1	Fine gravel	0.76	*2.80
1-.5	Coarse sand	8.55	8.36
.5-.25	Medium sand	35.04	20.11
.25-.1	Fine sand	19.26	10.72
.1-.05	Very fine sand	8.42	10.15
.05-.01	Silt	11.38	17.98
.01-.005	Fine silt	4.13	8.76
.005-.0001	Clay	10.59	11.60
	Total	98.13	96.48
Organic matter, water, loss		1.87	3.52

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
467	Shipley	10.59	1,244	4,767,000,000
476	Furnace Branch	11.60	1,549	5,386,000,000

* Including 1.08 per cent. larger than 2 millimeters.

The two samples from South Patapsco Neck show a larger percentage of clay than the lighter truck lands, and these soils are recognized as heavier lands and rather later than the early truck lands of Marley and Magothy. It is a great truck region, however, because it is adjacent to Baltimore, and the truck and vegetables can be taken to market by wagon at very much less expense and in better condition than if they were sent by boat or rail. These lands, also, can be depended upon for a constant supply of truck throughout the season, and while they come in competition more with truck from other parts of the state, still they have the advantage of more direct communication with the markets. Many of the truckers from this locality sell their products directly, without the intervention of middlemen or agents.

Mechanical analyses of truck lands from southern Maryland.

Diameter.	Conventional names.	270.	268.	145.
		South River Neck.	J. Birch.	Patuxent River.
mm.				
2-1	Fine gravel	0.32	0.04	1.78
1-.5	Coarse sand	5.81	1.97	7.63
.5-.25	Medium sand	40.63	28.64	38.35
.25-.1	Fine sand	28.93	39.68	21.80
.1-.05	Very fine sand	9.44	11.43	6.87
.05-.01	Silt	4.60	4.95	11.73
.01-.005	Fine silt	2.04	2.02	2.48
.005-.0001	Clay	7.63	8.79	7.92
	Total	99.46	97.52	98.56
Organic matter, water, loss		0.54	2.48	1.44

Mechanical analyses—Continued.

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
270	South River	7.63	903	3,450,000,000
268	J. Birch	8.79	1,007	3,955,000,000
145	Patuxent River	7.92	955	3,549,000,000

The two soils from South River Neck, represented in the table, are excellent truck lands and are particularly well adapted to peaches. The same may be said in a general way of the Patuxent River soils, but owing to the difficulty of transportation the soils represented by 145 have not been much improved.

These truck lands appear to be remarkably uniform in texture, and the slight differences, which appear in the percentage of clay and in the approximate number of grains per gram, are very sharply defined in the agricultural value and importance of the land. The soils having the lowest percentage of clay and the least number of grains per gram are, with the exception of those directly on the bay shore at the end of the river necks, invariably regarded as the earliest truck lands, and one can readily tell from the general appearance and texture of the soil to what class of lands the sample belongs. The light soils mature the crop earlier, but the heavier loam soils produce a larger yield per acre and generally a better development, and would be considered naturally stronger soils.

These soils are all too light for the profitable production of the staple crops, as the yield per acre would be extremely small and they could not compete with the stronger and heavier soils from other parts of the state and of the country. Their peculiar value lies in the fact that they can produce, during the spring and early summer, small fruits and vegetables earlier than they can be produced in other parts of the state, so that they have the advantage of good market prices. The reason for this is undoubtedly due to the physical structure of these soils, especially to the relation of the soils to water. It cannot be due directly to the amount of available plant food they contain, for no addition of mere plant food would make these soils as strong and productive as a limestone soil, unless the whole texture of the land was changed.

It has been shown in a diagram, page 53, that these light sandy soils can maintain, on an average, not more than 5 or 6 per cent. of water, and it has been shown that a good wheat land must maintain not less than 12 or 15 per cent. of water, and probably a good strong grass land should be able to maintain much more than this. These moisture determinations were made at Marley, near where samples 471 and 472 were taken.

A determination was made of the actual rate of movement of water through the subsoil in its natural position in the field, on Tick Neck, near where sample 583 was taken. The subsoil contains 37.29 per cent. of empty space and it took 3 minutes and 15 seconds for one inch in depth of water to pass through 3 inches in depth of subsoil, with an initial pressure of 2 inches in depth of water.

A determination was made of the rate of flow through the saturated soil at Armïger (563). The subsoil contained 41.25 per cent. of empty space and it took 2 minutes and 30 seconds for one inch in depth of water to pass through 3 inches in depth of subsoil, with an initial pressure of 2 inches of water.

A determination was made of the rate of flow through the saturated subsoil at Marley, near where samples 471 and 472 were taken. The subsoil contained 55.77 per cent. by volume of empty space; more than the samples from the other localities. An inch in depth of water passed through 3 inches in depth of the saturated subsoil in 1 minute and 30 seconds, under an initial pressure of 2 inches of water. In the wheat lands, as we will see later, the actual time required for an inch in depth of water to pass through 3 inches in depth of subsoil is very much longer than this, (43 minutes and over).

Stable manure is considered the very best fertilizer for these truck lands, and where this can be secured it is applied to the lands in large quantities. Lime is also largely used, but there must be sufficient organic matter in the soil for the lime to act on or it will "burn out" the land. Both the stable manure and lime, as we shall see later, would tend to make these soils more retentive of moisture, but the soils are so coarse and open in texture that large quantities of manure may be applied without fear of clogging the soil, and the effect of such manuring would be felt but a short time.

TOBACCO AND WHEAT LANDS OF SOUTHERN MARYLAND.

Tobacco and wheat have been staple crops in southern Maryland for many years. A grade of tobacco was produced there well adapted to the French and German markets, and large orders were placed with the Baltimore merchants for both of these countries.

It is claimed now that the lands have deteriorated from the continued cultivation of tobacco, and the quality of the tobacco is not so good as it was only a few years ago. Good prices may still be obtained for a good quality of leaf, but the prevailing prices are very low, as there is little market for the quality of tobacco generally produced.

It is claimed that the deterioration of these tobacco lands is largely due to lack of proper cultivation, owing to the scarcity and high price of labor, and to the lack of proper fertilization.

The wheat lands of southern Maryland, as stated in a previous section, are lighter in texture than the wheat and grass lands of northern and western Maryland, and the average yield per acre is much less. It is claimed that these wheat lands have deteriorated within recent years for lack of proper preparation and treatment of the land, due to the scarcity and high price of labor, to the low price of wheat, and to the fact that much of the land has been heavily mortgaged for the past twenty-five years.

It used to be the rule to apply lime every five years, and to depend on this and clover to keep up the land, but this rule is being neglected. Lime is applied more rarely, as there is little money to spend on fertilization, and the lands are becoming clover-sick.

This deterioration of the lands can not be due solely to loss of plant food, for the deterioration is accompanied by a marked change in the texture and appearance of the land, which is very apparent to the eye. There is the greatest possible difference in the appearance of a well kept field and of a soil which has deteriorated. Some very interesting problems are presented in the changes which evidently occur in the texture of these lands in the deterioration of soils, or in the improvement of such as have been once worn out and abandoned.

The wheat soils of southern Maryland appear to be confined principally to the Neocene formation, and to the terraces bordering the rivers in the lower part of the peninsula, which are classed with the Columbia terrace formation, although the soil is very different from the light, sandy, truck lands of the Columbia formation bordering the bay. Tobacco is produced on both of these formations, and also on the Eocene soils. By far the largest and most important area of the wheat and tobacco lands, however, is in the Neocene formation, and it is those lands which will be considered here.

Wheat and tobacco are commonly grown on the same land, in rotation periods of two or three years. The best lands for wheat, however, are the heaviest clay lands, while the finest quality of tobacco is produced on the lighter loams. The heavy clay lands produce a larger yield of tobacco per acre, but the plant has a coarse, thick leaf, which is sappy, and which cures green and will not take on color. The finest grade of tobacco is produced on the lighter loam soils, which are rather too light for the profitable production of wheat. The tobacco produces a small yield per acre on these soils, but the leaf has a fine texture, and in curing it takes on a good color and brings a much better price in the market. As a rule, the lighter the soil in texture the finer the quality of tobacco produced and the higher price it will bring per pound, but the less yield there will be per acre, so that there is a limit in the profitable production of the very finest grades on the very lightest lands, as the price is not sufficient to cover the small yield per acre.

The accompanying table gives the mechanical analyses of the subsoils of tobacco lands from a number of localities in southern Maryland:

Mechanical analyses of subsoils from southern Maryland, rather light for wheat but the finest tobacco lands.

Diameter.	Conventional names.	266.	258.	164.	260.	262.	162.
		Chaneyville.	Marlborough.	North Keys.	Nottingham.	Chaneyville.	Marlborough.
mm.							
2-1	Gravel	1.40	1.53	0.58	0.48	0.00	0.09
1-.5	Coarse sand	2.94	5.67	0.50	3.05	0.07	0.13
.5-.25	Medium sand	11.23	13.25	1.35	12.08	1.56	0.58
.25-.1	Fine sand	13.42	8.39	10.65	12.09	13.51	4.90
.1-.05	Very fine sand	19.32	14.95	37.71	19.17	37.73	26.78
.05-.01	Silt	17.59	28.86	22.00	23.09	18.82	33.12
.01.-.005	Fine silt	5.44	7.84	7.81	8.74	6.18	8.24
.005-.0001	Clay	10.72	14.55	16.02	18.42	18.79	21.81
	Total	97.06	95.04	96.72	97.12	96.67	95.65
Organic matter, water, loss		2.94	4.96	3.28	2.88	3.33	4.33

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
266	Chaneyville	10.72	1,370	4,891,000,000
258	Upper Marlborough	14.55	1,902	6,786,000,000
164	North Keys	16.02	2,016	7,338,000,000
260	Nottingham	18.42	2,126	8,263,000,000
262	Chaneyville	18.79	2,197	8,530,000,000
162	Upper Marlborough	21.81	2,638	10,065,000,000

The finest quality of tobacco is produced on the soils shown to have the smallest amount of clay and the smallest number of grains per gram in this table, while the heavier soils are much better for wheat and give a larger yield of tobacco per acre, but the quality of the tobacco is not so good, and it does not bring as good a market price. With the exception of 162, none of these soils would be considered very good wheat lands with the ordinary conditions of cultivation and manuring. They would be considered rather too light for the economical production of wheat. These lands are valued for wheat in proportion to the amount of clay contained in the subsoils, as shown in the table, but for tobacco the values are just reversed.

The strongest and best wheat lands appear to be confined to the diatomaceous earth horizon of the Neocene formation. The white diatomaceous earth can be found a few feet below the surface at all, or nearly all, the localities represented in the accompanying tables. The yellow clay of the wheat land appears to have been formed by the weathering of this earth, as in a number of railroad cuts and river bluffs they are seen to merge together, and in all cases where air has had access to the diatomaceous earth through cracks and root holes, a thin layer of the yellow clay has been formed. Diatoms are still found in most of these samples of the subsoils of the wheat and tobacco lands.

There are two classes of wheat lands. On the ridges and high plateaus, where washing has not occurred to any extent, the lands are rather light and loamy, the loam being usually from 2 to 4 feet thick and overlying the heavier clay. These lands are better for corn than the heavier lands, but are not so good for wheat and are too light in texture for grass. Where the underlying clay is exposed, as in the gently rolling lands, it makes a much stronger and better wheat soil and good grass land. The accompanying table gives the mechanical analyses of the subsoils from a number of localities, which represent very fairly the wheat lands of southern Maryland:

Mechanical analyses of subsoils of wheat lands from southern Maryland.

Diameter.	Conventional names.	250.	248.	245.	180.	155.	246.	141.	252.	184.
		Chaneyville, J. F. Talbott.	Davidsonville, P. H. Isreal.	Davidsonville, opposite church.	Plum Point.	Upper Marlborough.	½ mile west of Davidsonville.	Davidsonville, loam, T. S. Iglehart.	South River.	Popes Creek.
mm.										
2–1	Gravel	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00
1–.5	Coarse sand	0.07	0.22	0.28	0.00	0.40	0.56	0.23	0.25	0.46
.5–.25	Medium sand	0.98	2.76	0.98	0.48	0.57	31.26	1.71	3.39	6.61
.25–.1	Fine sand	12.22	12.85	1.74	3.06	22.64	4.62	6.08	10.65	12.19
.1–.05	Very fine sand	29.58	47.13	52.74	50.32	30.55	30.70	30.82	29.05	9.15
.05–.01	Silt	23.19	12.89	16.91	14.19	13.98	26.16	20.92	22.45	30.89
.01–.005	Fine silt	10.13	4.07	3.35	6.78	4.08	9.44	11.21	6.56	13.22
.005–.0001	Clay	19.14	19.19	19.57	20.28	21.98	22.53	23.78	23.92	24.45
	Total	95.31	99.11	95.82	95.11	94.20	95.27	94.75	96.27	96.97
Organic matter, water, loss		4.69	0.89	4.18	4.89	5.80	4.73	5.25	3.73	3.03

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
250	Chaneyville	19.14	2,453	8,918,000,000
248	Davidsonville, P. H. Isreal	19.19	2,097	8,452,000,000
245	Davidsonville	19.57	2,214	8,917,000,000
180	Plum Point	20.28	2,380	9,357,000,000
155	Upper Marlborough	21.98	2,493	10,228,000,000
246	½ mile west of Davidsonville	22.53	2,732	10,456,000,000
141	Davidsonville, loam, T. S. Iglehart	23.78	2,853	11,161,000,000
252	South River	23.92	2,681	10,933,000,000
184	Popes Creek	24.45	2,847	11,202,000,000

These lands make fairly good wheat lands, but it is about the limit of profitable wheat production, and a soil having less than 20 per cent. of clay, or approximately 9,000,000,000 grains per gram, is too light in texture and not sufficiently retentive of moisture for the economical production of wheat under the prevailing climatic conditions. This represents, however, merely the skeleton structure of the soil, and this could be so filled in and modified as to make it more productive, but experience has shown that a soil lighter than this has not sufficient body to warrant the expense of converting it into a good wheat land. The soils are too light for grass. They are valued as wheat lands about in the order in which they are given in the table, except that it would seem that 245 should have been given a higher place in the table, as it is considered a very fertile wheat land, but this may have been due to the sampling.

A determination was made of the time required for water to pass through the subsoil at South River, near where 252 was collected. The subsoil was found to contain 51.48 per cent. by volume of empty space. One inch in depth of water passed through 3 inches in depth of saturated subsoil in 43 minutes, with an initial pressure of 2 inches in depth of water.

The samples in the accompanying table are of strong wheat and grass lands of southern Maryland. They are considered the very finest type of wheat lands in that locality:

Mechanical analyses of subsoils of strong wheat and grass lands from southern Maryland.

Diameter.	Conventional names.	142.	247.	179.
		Davidsonville, clay.	Davidsonville, James Iglehart	Herring Bay.
mm.				
2-1	Fine Gravel	0.00	0.00	0.00
1-.5	Coarse sand	0.00	0.27	0.00
.5-.25	Medium sand	0.29	0.64	0.50
.25-.1	Fine sand	2.43	3.20	3.50
.1-.05	Very fine sand	23.56	22.58	36.28
.05-.01	Silt	29.23	26.25	19.04
.01-.005	Fine silt	6.36	10.42	6.78
.005-.0001	Clay	32.45	32.40	32.42
	Total	94.32	95.76	98.52
Organic matter, water, loss		5.68	4.24	1.48

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
142	Davidsonville, clay, T. S. Iglehart	32.45	3,604	15,148,000,000
247	Davidsonville, James Iglehart	32.40	3,537	14,903,000,000
179	Herring Bay	32.42	3,369	14,433,000,000

These three samples were taken from very rolling lands, where the loam, if it had ever accumulated, had been removed by washing, leaving exposed the yellow clay which seems to underlie all the wheat lands.

Very recently the U. S. Geological Survey has made a geological survey of this locality, and from a manuscript map which they have kindly supplied it would appear that they have been able to separate the Neocene formation in this locality into Lafayette and Chesapeake. The Lafayette is shown as covering the high hills and plateaus, apparently where our loam samples were secured. The Lafayette formation is hardly more than 2 to 4 feet thick at this place, and is made over out of the diatomaceous earth material, which would account for the diatoms found in the subsoil. The Lafayette formation covers the ridge lands further down the peninsula with the coarse, sharp sand of the pine barrens. This geological data will necessitate a further and more careful collection of soil samples in this locality, to see if these two grades of wheat land correspond closely with the two horizons of the Neocene formation; but this whole work shows the intimate relation of geology to agriculture, in the area and distribution of the principal soil formations and the necessity of thorough geological work as a basis for soil investigations.

There is a very marked relation between the agricultural value of these lands and the texture and general appearance of the soils. If the soils are in a moderate condition of cultivation, in which the arrangement of the grains can be assumed to be sensibly constant, the agricultural value increases quite regularly with the percentage of clay, and the approximate number of grains per gram. The yield increases, however, in nearly all cases, and with most crops, at the expense of the quality of the crop produced. In the case of tobacco and truck, as the quality or time of maturity is of more importance than the quantity of crop produced, the lands are valued, within certain limits, as the soil is lighter in texture and contains less clay and fewer grains per gram. It is not a matter of the chemical composition of the soil, or of the amount of available plant food in the soil, which determines this local distribution of crops, but it is a matter of the texture of the soil and especially of the relation of the soils to water, and the amount of water which they can maintain for the crop under existing climatic conditions.

Lime has been considered the very best fertilizer for these wheat lands, but lime with plenty of organic matter in the soil "for the lime to act on," otherwise, it will "burn out the land," so that where lime is applied, as it should be every few years, clover or some green manuring is considered a necessary adjunct. We shall see that this combination would tend to make the soils more retentive of moisture.

There has always been a peculiar prejudice against the use of high grade fertilizers in southern Maryland. They are rarely used on the wheat lands, especially where lime and clover can be applied. Large quantities have been used on the tobacco lands, but the deterioration of these tobacco lands is very frequently attributed to the use of the high grade fertilizers.

When Peruvian guano was introduced, as one of the first of the high grade fertilizers, it was used quite freely for tobacco, but it was claimed that it was, in the end, injurious to the lands. It was said that for the first two or three years it acted as a stimulant and increased the yield of crop, but that the land soon became exhausted and was poorer than before. There has been no general recognition of this fact by agricultural chemists, for it has been argued that the continued application of plant food could not impoverish a soil, but it would certainly seem that the farmers were right in this, and that the injudicious use of high grade fertilizers may very likely have a permanent effect upon these soils, by changing the arrangement of the soil grains and changing the relation of the soils to water, which would be highly injurious to succeeding crops. This matter presents one of the most interesting problems in these soil studies of southern Maryland.

The samples which have been described and of which the mechanical analyses have been given in the foregoing tables, are of representative soils and from what is considered to be typical and representative localities of the different soil formations. Other samples have been collected of local interest, and there is a considerable amount of material on hand for the study of the change in texture which has evidently occurred in the deterioration of some of these lands, but there has been no time to work them up for this report.

WHEAT LANDS OF THE RIVER TERRACES.

The accompanying table gives the mechanical analyses of the subsoils from four localities of the fertile river terraces of southern Maryland:

Mechanical analyses of subsoils of wheat land.

RIVER TERRACE.

Diameter.	Conventional names.	199.	201.	203.	205.
		Benedict.	St. Marys.	St. Marys.	Opposite. St. Marys.
mm.					
2-1	Fine gravel	0.38	0.44	2.01	0.41
1-.5	Coarse sand	2.72	1.05	5.24	0.42
.5-.25	Medium sand	11.64	2.67	1.75	1.64
.25-.1	Fine sand	7.23	5.03	2.17	3.45
.1-.05	Very fine sand	6.74	9.75	2.45	9.48
.05-.01	Silt	33.92	34.82	37.21	41.88
.01-.005	Fine silt	10.62	14.52	15.52	11.98
.005-.0001	Clay	23.45	25.03	29.27	26.24
	Total	96.70	93.31	95.62	95.50
Organic matter, water, loss		3.30	6.69	4.38	4.50

No.	Locality.	Clay.	Surface. area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
199	Benedict	23.45	2,765	10,737,000,000
201	Saint Marys	25.03	2,889	11,936,000,000
205	Opposite Saint Marys	26.24	3,188	12,205,000,000
203	Saint Marys	29.27	3,509	13,578,000,000

These river terraces border the Potomac River and its tributaries in the lower part of the peninsula, and are considered very strong wheat lands. They are classed geologically with the Columbia terrace formation, but, as will be seen from the mechanical analyses and as shown from the agricultural value of the lands, they are very much stronger soils than those of the same formation on the bay shore, which form the early truck lands between Baltimore and Annapolis. The terraces have an elevation of from 20 to 60 feet above tide and are about ½ mile wide, with the Lafayette formation rising beyond this into the pine barrens of the higher lands further inland. The lands have good body and are capable of a very high state of cultivation, and many of them are maintained in a very good condition. Some of the land around Saint Marys has been under cultivation for two hundred years without apparent deterioration, although there is nothing at all peculiar in the appearance of the land to indicate any unusual conditions. The soil is about 6 or 8 inches deep, but neither the soil nor subsoil appear to have more organic matter than is usual in the lands of southern Maryland, nor do they appear different from the same class of lands elsewhere. They have been taken care of and have been very intelligently handled.

TRUCK AND WHEAT LANDS FROM SHIPLEY.

Very interesting conditions, showing the relation of the texture of the soil to the local distribution of plants, are presented in the soils represented by their mechanical analyses in the accompanying table:

Mechanical analyses of truck and wheat subsoils—W. A. Shipley, Shipley Station.

Diameter.	Conventional names.	472. Early truck, Marley.	467. Truck and small fruit.	478. Peas, tomatoes, cabbage, wheat.	480. Strong wheat and grass.
mm.					
2-1	Fine gravel	0.49	0.76	2.05	0.00
1-.5	Coarse sand	4.96	8.55	3.31	0.38
.5-.25	Medium sand	40.19	35.04	5.41	1.07
.25-.1	Fine sand	27.59	19.26	2.89	0.78
.1-.05	Very fine sand	12.10	8.42	6.06	3.41
.05-.01	Silt	7.74	11.38	40.15	43.08
.01-.005	Fine silt	2.23	4.13	13.14	13.81
.005-.0001	Clay	4.40	10.59	23.84	30.21
	Total	99.70	98.13	96.85	92.80
	Organic matter, water, loss	0.30	1.87	3.15	7.20

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
472	Early truck, Marley	4.40	615	1,950,000,000
467	Truck and small fruit	10.59	1,244	4,767,000,000
478	Peas, tomatoes, cabbage, wheat	23.84	2,242	10,923,000,000
480	Strong wheat and grass	30.21	3,479	14,457,000,000

472 represents the very early truck lands of Marley, which have already been described. Marley is about 3 or 4 miles in a direct line

from Shipley Station. The other three soils are all at Shipley Station, and are on the same farm and are only a few hundred feet apart, so that all the soils are under the same meteorological conditions. 480 is a strong grass and wheat land, from a ridge having an elevation of about 160 feet. This sample was taken in a heavy grass sod which has stood for a number of years. It would be classed anywhere as a strong wheat soil and a very good grass land. 478 came from a level plateau or terrace, just under the ridge, and was evidently formed of the same material. It is a much lighter soil than that on the top of the ridge, but is still a good wheat land. It is too heavy for early truck and for sweet potatoes and canteloupes. It is considered good tomato, corn, and cabbage land, although it does not ripen the crops so early as the lighter soils. Peas do well on this land, but they cannot be grown two years in succession, for the large amount of nitrogenous matter in the roots and vines makes the soil very close and heavy, and the second year there is a large amount of pea vines but a very small crop of peas is obtained from them. Wheat is nearly always sown after the peas, then grass, followed by corn, and then peas again. Some such rotation as this is necessary to keep the land open and in good condition. 467 is the regular truck land of this locality, well suited to truck and small fruit. It is a coarse, sandy soil, but not so light in texture nor as early as the lands at Marley. The productiveness of these lands increases with the amount of clay they contain and the number of grains per gram.

It cannot be doubted that the local distribution of plants on these soils is due to the texture of the land, and very largely upon the relation of the soils to water. No better illustration can be found of the fallacy of a very common impression of the theory of fertilization than in these soils. It is not that the strong clay soil (480) is necessarily deficient in any particular kind of plant food that sweet potatoes and canteloupes cannot be successfully grown, and further, if sweet potatoes and canteloupes are to be grown upon this land the conditions of treatment should be just the reverse of what would be required for the best development of wheat. For the melons the soil must be made more loamy and less retentive of moisture, while for wheat and grass the soil must be made, if anything, closer and more retentive of moisture. Tomatoes raised on a heavy soil, like (480), in which there is such an abundant water supply, would be likely to run to weed, that is, to produce a very large and rank growth of vine but with little fruit, and it would be late in coming to maturity, just as in a greenhouse a florist can make a geranium bloom quite freely by keeping the soil rather dry, or he can push it to a luxuriant development of foliage, with no tendency to flower, by keeping the soil more moist. Obviously, the same treatment could not be expected to have the same results for all crops on any one of these soils, and the same plant might require very different conditions of manuring and treatment on these four different soils.

It would be admitted by practical men that 467 is well adapted to small fruits, but that 472 is rather light in texture and 480 is too heavy for the best development of such a crop. Obviously, the treatment best adapted to one soil would not give the same results on the other, for the conditions of growth which it is desired to secure would be a mean between these two extremes.

SAMPLES OF CLAY.

Very interesting conditions are found in the Potomac formation; a narrow belt of barren clay hills extending across the state from Washington through Baltimore to the Delaware line. These variegated clays are so close in texture as to be almost impervious to water, and quite unsuited to the growth of agricultural crops. The movement of water through them is so extremely slow that a plant would suffer for lack of sufficient water while the soil might show a high water content. The clay is used at the potteries for burning both porous tile and stoneware, and it is so impervious to water that it is used for puddling and for diverting water from the gutters in the repair of streets.

The accompanying table gives the mechanical analyses of three samples of clay:

Mechanical analyses of samples of clay.

Diameter.	Conventional names.	304.	305.	288.	303.
		Red clay, tile.	Red clay, puddling.	Helderberg limestone.	Blue clay, stoneware.
mm.					
2-1	Fine gravel	0.00	0.31	1.34	0.00
1-.5	Coarse sand	0.00	0.82	0.33	0.00
.5-.25	Medium sand	0.50	2.69	1.08	0.29
.25-.1	Fine sand	2.63	3.23	1.02	1.27
.1-.05	Very fine sand	9.62	8.89	6.94	8.93
.05-.01	Silt	25.13	26.17	29.05	20.16
.01-.005	Fine silt	13.44	11.18	11.03	16.72
.005-.0001	Clay	42.34	42.36	43.44	50.02
	Total	93.76	95.65	94.23	97.39
Organic matter, water, loss		6.24	4.35	5.77	2.61

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
304	Red clay, tile	42.34	4,737	20,072,000,000
305	Red clay, puddling	42.36	4,566	19,447,000,000
288	Helderberg limestone	43.44	4,575	19,638,000,000
303	Blue clay, stoneware	50.02	4,905	22,639,000,000

There is also given, for comparison, the mechanical analysis of a very strong and fertile wheat subsoil of the Lower Helderberg formation. It will be seen that this is almost identical in texture with the red clay used in puddling. The impervious clays have no more of this fine material in the clay group, and no more grains per gram than the limestone soil, but the one is too close in texture and too retentive of moisture, and will dry into a hard, stone-like mass, while the other, although a strong clay soil, is friable and readily permeable to water.

A few drops of strong ammonia added to the water which passes through the limestone soil will make this quite as impervious as the other clays, and this change in the texture of the soil will be due to a rearrangement of the soil grains, the change being quite apparent to the eye. There is no question but that the trouble with these impervious clays is that they are too close and too retentive of moisture, and that this is due, not to an unusual amount of clay, but to the arrangement of the soil grains. To increase the agricultural value of these lands they must be made lighter in texture and less retentive of moisture, and this can probably be done by the judicious use of fertilizers and manures, accompanied by underdrainage and proper conditions of tillage and cultivation; on the other hand, it will be no very difficult thing, by injudicious fertilization or treatment of the land, to convert the limestone soil into an impervious clay which would be turned out as a barren waste.

The whole problem of the soils, as presented in southern Maryland, makes it appear that the deterioration of lands is due to or is accompanied by a change in the arrangement of the soil grains, changing the relation of the soil to the circulation of the water. This change in the appearance or texture of the land is quite apparent to the eye, and one can judge of the condition of the land by the general appearance of the soil.

It would appear as a result of this work that the subsoil of good grass land under prevailing climatic conditions should contain not less than 30 per cent. of clay, or about *twelve thousand million* grains per gram, good wheat land not less than 20 per cent. of clay, or about *nine thousand million* grains per gram, and early truck not over 10 per cent., or about *four thousand million* grains per gram; *provided*, these grains have a certain mean arrangement, and that this skeleton structure contains an average amount of organic matter.

It has taken a long time to collect this material and arrange and classify it to give a basis for further work. It has not been possible to go over the field and make the actual determinations of the rate of flow of water through these subsoils, except in the few cases which have been given, and in working up the methods in the laboratory. This is the most important work to be taken up, now that the material has been collected, and if the opportunity is given this will be the next line of work to be undertaken, to study the actual relation of these soil formations to water and the effect thereon of manures and fertilizers.

Until this work is done and the actual determinations of the rate of flow can be given it will be unnecessary to give in detail the calculated relative rate of movement of water through these different soils.

There has not been sufficient work done as yet in the soils of western Maryland to permit of a fuller discussion than will be given in the type samples.

TYPE SUBSOILS.

A number of type samples have been prepared and analyzed, showing the average composition of all the samples collected from the principal agricultural soils in southern and western Maryland, as shown in the accompanying table.

Mechanical analyses of type subsoils.

Diameter.	Conventional names.	276.	284.	286.	290.	280.	278.	282.	238.	289.	288.
		Pine barrens.	Truck.	Tobacco.	Oriskany, "fine earth."	Wheat.	River terrace.	Triassic.	Catskill, "fine earth."	Shales, "fine earth."	Helderberg limestone.
mm.											
2-1	Fine gravel	*4.87	1.34	1.36	0.64	0.00	1.60	0.00	0.00	0.05	†1.34
1-.5	Coarse sand	9.15	8.24	2.13	0.81	0.42	1.51	0.23	0.11	0.16	0.33
.5-.25	Medium sand	38.37	34.77	7.78	3.50	1.81	4.15	1.29	0.42	0.80	1.08
.25-.1	Fine sand	33.28	19.94	16.57	23.97	8.59	4.84	4.03	2.63	2.01	1.02
.1-.05	Very fine sand	3.52	11.11	19.83	34.76	32.06	8.54	11.57	11.35	6.70	6.94
.05-.01	Silt	3.47	12.15	25.41	10.03	23.65	44.92	38.97	40.23	31.63	29.05
.01-.005	Fine silt	1.55	4.17	4.52	3.03	6.77	5.78	8.84	10.90	14.24	11.03
.005-.0001	Clay	3.75	7.45	17.95	20.30	22.85	25.85	32.70	33.32	39.36	43.44
	Total	97.96	99.17	95.55	97.04	95.85	97.19	97.63	98.96	94.91	94.23
Organic matter, water, loss		2.04	0.83	4.45	2.96	4.15	2.81	2.37	1.04	5.09	5.77

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
276	Pine barrens	3.75	496	1,692,000,000
284	Truck	7.45	971	3,266,000,000
286	Tobacco	17.95	2,102	8,258,000,000
290	Oriskany, "fine earth"	20.30	2,173	9,154,000,000
280	Wheat	22.85	2,602	10,358,000,000
278	River terrace	25.85	2,924	11,684,000,000
282	Triassic red sandstone	32.70	3,593	14,736,000,000
238	Catskill, "fine earth"	33.32	3,669	14,839,000,000
289	Shales (Hamilton, etc.), "fine earth"	39.36	4,411	18,295,000,000
288	Helderberg limestone	43.44	4,575	19,638,000,000
....	Trenton chazy limestone	53.02	5,574	24,653,000,000

* This includes 1.81 per cent. coarser than 2 millimeters.
† This includes 0.82 per cent. coarser than 2 millimeters.

The tables are substantially as published in the Fourth Annual Report of the Maryland Agricultural Experiment Station, except that it has been found that a sample containing a large percentage of clay had been accidentally introduced into the truck type, and so few localities were represented that this made a great difference. The present type of truck soil is from twenty-eight localities. This table includes all of the principal agricultural soils in southern and western Maryland, except the very important soil of the Trenton limestone formation, represented here by only a single sample, but it does not include any of the soils of the Eastern Shore or any of the soils of the crystalline rocks of the Piedmont Plateau in northern-central Maryland.

The soils thus arranged according to the amount of clay they contain and the approximate number of grains per gram, which gives the texture of the soil, are arranged in the order of their relative agricultural value.

The approximate extent of surface area, in square centimeters per gram, is given in detail in the accompanying table for a number of the soil types and the approximate number of grains per gram, to show the relative value of each of the separations.

Surface area (sq. cm.) per gram of subsoil.

Diameter.	Conventional names.	276.	284.	286.	280.	279.	282.	288.
		Pine barrens.	Truck.	Tobacco.	Wheat.	River terrace.	Triassic red sandstone.	Helderberg limestone.
mm.								
2-1	Fine gravel	0.5	0.2	0.2	0.0	0.2	0.0	0.1
1-.5	Coarse sand	2.8	2.5	0.7	0.1	0.5	0.1	0.1
.5-.25	Medium sand	23.6	21.2	4.9	1.1	2.6	1.0	0.7
.25-.1	Fine sand	43.9	26.0	22.4	11.6	6.4	5.3	1.4
.1-.05	Very fine sand	10.8	33.8	62.5	100.9	26.5	35.8	22.2
.05-.01	Silt	26.7	92.5	200.7	186.2	348.7	301.4	232.7
.01-.005	Fine silt	47.7	127.0	142.8	213.2	179.5	273.5	353.4
.005-.0001	Clay	339.8	667.3	1,668.0	2,089.0	2,300.0	2,976.0	3,965.0
	Total	495.8	970.5	2,102.2	2,602.1	2,924.4	3,593.1	4,575.3

Approximate number of grains per gram of subsoil.

Diameter.	Conventional names.	276.	284.	286.	280.
		Pine barrens.	Truck.	Tobacco.	Wheat.
mm.					
2-1	Fine gravel	7	3	3	0
1-.5	Coarse sand	160	142	38	7
.5-.25	Medium sand	5,356	4,794	1,114	258
.25-.1	Fine sand	45,700	27,050	23,320	12,050
.1-.05	Very fine sand	61,380	191,500	354,500	571,200
.05-.01	Silt	945,900	3,270,000	7,101,000	6,588,000
.01-.005	Fine silt	27,030,000	71,830,000	80,790,000	120,700,000
.005-.0001	Clay	1,664,000,000	3,267,000,000	8,170,000,000	10,230,000,000
	Total	1,692,088,503	3,342,323,489	8,258,269,975	10,357,871,515

Diameter.	Conventional names.	278.	282.	288.
		River terrace.	Triassic red sandstone.	Helderberg limestone.
mm.				
2-1	Fine gravel	3	0	12
1-.5	Coarse sand	26	4	60
.5-.25	Medium sand	583	181	157
.25-.1	Fine sand	6,701	5,556	1,456
.1-.05	Very fine sand	150,200	202,600	125,900
.05-.01	Silt	12,340,000	10,670,000	8,231,000
.01-.005	Fine silt	101,600,000	154,900,000	199,900,000
.005-.0001	Clay	11,570,000,000	14,570,000,000	19,430,000,000
	Total	11,684,097,513	14,735,778,341	19,638,258,585

It will be seen from these tables that the clay group has a most important influence on the texture of the soil, as shown in these calculations. In the extent of surface area it is far ahead of the other separations, although the effect of the coarser grades is still quite apparent. In the approximate number of grains per gram, which, according to these views, determines the extent of subdivision of the empty space in the soil, the clay group has by far the greatest value, and this and the fine silt practically determine the real texture of the subsoils, provided the grains have the same mean arrangement. The reason for this is found in the extremely small size of the grains of clay, so that a percentage of clay means a vast number of soil grains and a very large extent of surface area.

Assuming the amount of empty space for these subsoils, as given, the relative rate of flow of water through a certain depth with a uniform water content (12 per cent.), is given in the accompanying table, as calculated by the formulæ already given.

No.	Soil.	Space.	Water-content.	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	12	8
284	Truck	45	12	16
286	Tobacco	50	12	33
290	Oriskany	50	12	35
280	Wheat	55	12	45
278	River Terrace	55	12	49
282	Triassic	55	12	56
238	Catskill	55	12	58
289	Shales (Hamilton, etc.)	60	12	81
288	Helderberg limestone	65	12	100

With this uniform water content, if an inch in depth of water passed through the Helderberg limestone in 100 minutes, it would take about 45 minutes for the same quantity of water to pass through the type of wheat land of southern Maryland. With the same rainfall, therefore, and the same amount of water falling on each of these soils, the water will pass down through the light lands much quicker than through the heavier soils, providing the soils are short of saturation.

Some time after a rain when the excess of water had passed down through the light lands, and the rate of movement was about the same in all of the soils, the water content of these lands would be about as given in the next table.

No.	Soil.	Space.	Water-content.	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	5.3	101
284	Truck	45	6.2	103
286	Tobacco	50	8.4	102
290	Oriskany	50	8.6	101
280	Wheat	55	9.4	100
278	River terrace	55	9.6	100
282	Triassic	55	10.0	101
238	Catskill	55	10.1	100
289	Shales (Hamilton, etc.)	60	11.2	100
288	Helderberg limestone	65	12.0	100

This would be approximately the relative amount of water found in each of these subsoils some time after a soaking rain, and it agrees very well with the few actual moisture determinations which have been made in these soils. There is little doubt that these values, based on purely theoretical considerations, will be sustained, in the main, by actual moisture determinations and that they will give an expression of the texture of the land. The mean arrangement of the grains in the undisturbed subsoil of these great formations is probably not very different, except in special cases, as in the impervious clays of the Potomac formation or for local conditions, and it is probable that the amount and condition of the organic matter in the undisturbed subsoil of these great soil areas are sensibly constant and that their effect will not greatly differ, except under artificial conditions of cultivation and manuring.

There are undoubtedly exceptions to this, as may be seen very plainly in the Potomac clays and in the shales in the western part of the state, but these exceptions are due to conditions which can be readily recognized and which, indeed, are made apparent by the departure of these soils from the conditions which have been assumed.

The relations of these soils to water as shown by these calculations, and as it is believed will be shown by actual moisture determinations, are as different as in the artificial conditions of greenhouse culture.

In greenhouse culture the development of the plant can be largely controlled by judicious watering. Water may be readily added or withheld from different classes of plants, or for different kinds of development as needed, and the whole art of greenhouse culture is in the judicious control of the temperature and the moisture of the soil. Different classes of plants undoubtedly require different treatment for their best development. In field culture water can not be so readily added or withheld for certain classes of plants or for certain kinds of development, but we find that under the same rainfall these different soil formations have such different relations to water that they are able in themselves to maintain very different conditions of moisture for the plants, quite as different as in the artificial conditions of greenhouse culture, so that the conditions in these different soil formations are best adapted to particular kinds of plants; and we have here, it would appear, the reason for the local distribution of plants under prevailing climatic conditions.

It may be suggested that if water can move through the light truck lands, containing 5 per cent. of moisture, in the time it moves through the heavier limestone soils, containing 12 per cent. of water, as shown in these calculations, that the light truck lands should be able to supply the wheat crop with sufficient water as readily as the heavier clay soil; but when water descends in the soil the forces pulling it down are surface tension and gravity. But where it has to be pulled up to the plant the only force to pull it up is the surface tension, and this has to act *against* gravity. There is much less water surface to contract in the light, sandy lands, so that if 100 pounds of water are needed by the wheat crop in a given time there will be very much less water surface to contract—that is, much less force to pull the weight of water up to the crop in the light land than in the heavier soil.

Another interesting problem is suggested here in the application of these principles to the study of the relation of the soils to water. If the empty space within the soils is completely filled with water, as in a perfectly saturated soil, the amount of space will be an important factor in the rate with which this water can be removed, and the light, sandy lands, having much less space and a much smaller capacity for water, may be slower than the heavier soils in draining off the excess. This is shown in the accompanying table, and may very likely account for the matter of very common experience that crops suffer more in excessively wet seasons in light lands than they do on heavier soils.

No.	Soil.	Space.	Water-content (saturation).	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	20.10	74
284	Truck	45	22.41	87
286	Tobacco	50	27.42	121
290	Oriskany	50	27.42	130
280	Wheat	55	31.55	109
278	River terrace	55	31.55	119
282	Triassic	55	31.55	137
238	Catskill	55	31.55	140
289	Shales (Hamilton, etc.)	60	36.14	123
288	Helderberg limestone	65	41.22	100

These calculations of the relative rate with which water will move within these different subsoils are based solely on the skeleton structure. The influence of the organic matter is not considered, and the soil grains are assumed to have the same mean arrangement. These two factors, the amount of organic matter and the arrangement of the soil grains, are probably nearly alike under the normal conditions which prevail in these great soil formations, as has already been pointed out, but if they have not the same effect in the different soils they will undoubtedly make the difference in the relations of these soils to the circulation of water still wider than the values we have assigned. Each of these factors requires a distinct line of investigation, and this is necessary to the practical use and application of this work.

If it is thought that not sufficient importance has been given to the chemical composition of the soils in this treatment of the subject, it must be remembered that if it is admitted that the judgment of the practical farmer of the value of his lands is based on the general appearance or texture of the land which determines the relation of the soil to water, then this factor is the controlling cause of plant growth and distribution, and is of first importance in the treatment and improvement of the land, and it is only through the study of the texture of the soil that the theory of fertilization will be made clear.

EFFECT OF FERTILIZERS ON THE TEXTURE OF THE SOIL.

In the improvement of a soil the question should be asked, how do the conditions differ from the best conditions for the kind of crop or the kind of development desired, and this question must be answered by the effects which are usually very apparent to the eye. The soil may be too dry or leachy, or it may be too retentive of moisture. This may be apparent to the eye in the texture of the soil, or it may be shown in the growth, vitality, and development of the plant.

Take the case of the soil from the sand hills of South Carolina, which has been referred to in a previous section. The growth of the plant is very small, but it puts on a large amount of fruit in proportion to the size of the plant and the amount of food material which has been stored up, and it ripens the crop quite early. Both of these latter qualities are very desirable. The size of the plant, however, shows that the soil is either not sufficiently retentive of moisture, or it is so very retentive and impervious that it can not supply the moisture fast enough for the needs of the plant. The texture of the soil shows that the soil is not sufficiently retentive of moisture, and that it is in this direction, rather than the other, that the trouble lies, and that to improve the condition of the land this soil must be made more retentive of moisture. On the other hand, the red land is rather too close and too retentive of moisture; it maintains such an abundant supply of water that the plants develop a very large amount of foliage and grow to a large size, and while they produce a large yield per acre of seed cotton, there is not nearly so much crop produced in proportion to the amount of food material stored up as with the crop on the sandy land. There is a tendency also for the crop to be late in maturing. It requires a careful diagnosis to determine what is the trouble with the land, just as a physician must be able to judge from the symptoms what is the cause of the trouble with the patient; and he must act on this for the improvement of the system.

In greenhouse culture, an experienced florist can tell from the development and appearance of the plant whether it has received the proper treatment; and so with field crops, from the appearance of the plant, the kind of development, the texture of the leaf, the vitality of the plant, and the diseases or insect ravages to which it is subjected, all are very plain indications of the conditions of the soil, and it is from these symptoms that one must judge of the cause of the trouble, and it is in this line that the improvement of the land must be worked out.

To change the physical condition and texture of a soil so as to make it more retentive of moisture, there are two possible lines of procedure which may be clearly recognized and defined. The soil grains may be pushed further apart, not necessarily so that the volume of empty space will be increased, but that the fine grains of clay shall be pushed further out from the larger grains of sand, so that the grains will have a more symmetrical arrangement within the soil, or, if the grains have already such an arrangement as to give the full value to the clay, this skeleton structure can be filled in with organic matter by precipitation of organic matter within the soil.

The first of these principles can be illustrated in the opposite effects of ammonia and lime on fine particles of clay suspended in a liquid. If a drop of the turbid liquid containing a trace of ammonia be placed under the cover glass of a microscope, the fine particles of clay suspended in the liquid can not come close together, or, if they do, they are repelled. If, on the other hand, a trace of lime is added to the turbid liquid, the fine particles of clay and silt gather together in light flocks, and can not only approach each other, but are held together by some force.

The effect of ammonia in rearranging the grains in the soil has already been referred to. It is very probable that the chemical composition of the soil moisture will determine the distance apart of these fine silt and clay particles, so that they may come closer together when some fertilizers are added to the soil, or be pushed apart when others are applied. These movements could readily take place in a soil containing only a moderate amount of moisture, for the film of water around the grains would be much thicker than the diameter of the grains of clay, so that the latter would be immersed in what would be, relatively, a liquid of some depth.

This matter can probably be made the subject of experimental verification, and, indeed, the apparatus has been ready here for some time to determine this point, whether two surfaces immersed in a liquid can come closer together under a constant weight when certain fertilizing materials are present than when others have been dissolved in the water. Measurements of this kind are to be made, as preliminary work to the study of the effect of fertilizers on the arrangement of the soil grains. Fertilizers are certainly known to have some such physical effect as this on the soil, although the cause has never been worked out in this detail, nor has the effect itself ever been considered much in soil investigations, in the effect it would have on the soil and crop.

The effect of organic matter in retarding the rate of flow and making the soil more retentive of moisture, is much more apparent than the rearrangement of the soil grains. If a filtered extract of stable manure is poured on to a soil contained in a glass tube, the organic matter will be precipitated in light, flocculent masses within the soil, and the liquid will run through quite colorless. If the coarse, sandy soil of the sand hill formation in South Carolina, or of the truck lands in Maryland, are to be improved, there is nothing so good as stable manure to apply to the land, especially if the soil is already quite deficient in organic matter, as is usually the case. If a quantity of such a soil be placed in a glass tube with a cloth tied over the under end, and a filtered extract of stable manure poured on the soil, the liquid will pass through quite colorless, and the rate of movement will get slower and slower until, if sufficient organic matter is used, the soil can be made quite impervious to water.

The precipitation of the organic matter from solution, and the segregation of the solid matter into light, flocculent masses, can be watched through a microscope focused against the side of the tube.

If coarse, sharp building sand is used, the organic solution may pass through unaffected, but if lime or some other fertilizing materials are added to the sand, the precipitation occurs as in a soil proper. If the lime is mixed with the upper inch of sand, this will assume the dark appearance of a soil resting on a light, sandy subsoil, with a sharp line of demarkation between them, so that in such a soil, naturally deficient in lime and iron compounds, an application of lime or of some similar substance which coagulates the organic matter would be necessary to bring out the full effect of the organic manuring. As a matter of fact, there is no soil which responds so readily to lime as these light, sandy lands, when sufficient organic matter is added,or is present, for the "lime to act on."

The lime precipitates the nitrogenous matter of the stable manure from solution, and in this case, at any rate, it is this coagulated nitrogenous matter which makes the soil more retentive of moisture, and it is this nitrogenous matter, alone, of all forms of organic matter, which is valued as a fertilizing material. There seems no reason to doubt that if the carbo-hydrates were readily precipitated from solution in these light, flocculent masses that they would have the same effect in retarding the rate of flow of water through soils and in making the soil more retentive of moisture, and that they would then have nearly the same agricultural value.

Many organic substances can be coagulated or precipitated from solution by lime or various alkaline or saline bodies, while others would not be affected by these, but would be coagulated by acids and a different class of material. With this view of the matter, therefore, it would not be expected that different forms of organic matter would have the same effect on the same soil, or that the same kind of organic matter would have the same effect on different soils. This view of the matter makes it evident why stable manure and lime have always been given a value out of all proportion to the amount of plant food which they contain, and why a comparatively small application of these and other fertilizing materials often has an effect on the crop out of all proportion to the plant food they contain.

Some experiments have been carried on to study this effect of fertilizers on the movement of water through soils, both in the laboratory and in the field. In the laboratory, 8-inch Argand lamp chimneys have been used, 2 inches in diameter. A subsoil containing 26 per cent. of clay has been used in most cases, and a depth of 6 inches with 50 per cent. by volume of empty space. In the field work the fertilizers were thoroughly mixed with the soil to a depth of 6 inches, and samples will be taken in the undisturbed subsoil from below this for the actual determination of the rate of flow of water several times during the growing season. The work has not progressed far enough to be discussed in detail in this report, but it is giving very interesting results, and showing a very marked effect of fertilizers on the relation of soils to water.

One interesting fact brought out in these laboratory experiments is that when successive quantities of water are passed through a soil in a tube the rate becomes slower and slower. In one case, with 47 per cent. by volume of empty space in the soil, the rate decreased from 57 minutes to 169 minutes when eight successive quantities, of 100 cubic centimeters of water each, had been passed through. Another time, with 50 per cent. by volume of empty space, the rate decreased from 36 minutes to 265 minutes when eighteen successive quantities, of 100 cubic centimeters of water each, had been passed through. When a filtered extract of stable manure was passed through a similar lot of soil the rate decreased to about 2,000 minutes after six successive quantities of the extract had passed through, and the rate became so slow that the work could not be carried further. Lime or muriate of potash when added to the soil alone had little effect on the rate of flow, but seemed to increase it a little. When lime was added to the soil and an extract of organic matter then passed through, the rate at first was slower than when the lime had not been added, but it did not decrease as rapidly when successive quantities of organic extract had been passed through, and lime, acid phosphate, and kainite seemed to prevent the very marked effect of the organic matter alone; so, while lime or some similar substance is necessary to bring out the effect of organic matter in a sharp building sand, still, in the presence of lime and in this soil containing 26 per cent of clay and presumably a considerable amount of iron compounds, the organic matter did not have nearly as much effect on the soil when lime was present as when it was applied alone. It would seem that there must be some such difference to explain the difference in the effect of lime on stiff, heavy clays, and on light, sandy soils.

Dried blood, dried tankage, dried fish, and cotton-seed meal all had a very marked effect in retarding the rate of flow. Ammonium sulphate decreased the rate, but not very much; nitrate of soda decreased the rate very remarkably, and made the soil almost impervious to water. This can hardly be due to a precipitation, as in the case of the organic matter, and must, probably, be due to a rearrangement of the soil grains, as in the case of ammonia.

These results are preliminary and are not sufficient for a detailed discussion, but they certainly point out a very remarkable effect of these fertilizing materials on the texture of the soils and the relation of soils to water, and point out a line of work which will be necessary for the interpretation of the results of plot experiments, and for working out the true theory of fertilization.

The soil appears to a casual observer as a coarse and inert mass, popularly known as "earth" or "dirt"; it seems hardly as though it could be affected by any simple change of conditions. It is, on the contrary, extremely sensitive to even unappreciable changes of conditions, and the relation of soils to water is so extremely sensitive that there is little wonder that the soil is often injured by injudicious treatment, but the wonder is that it is not more often ruined by the treatment it receives.

In this moisture work it is extremely difficult to fill the same tube twice over with a similar soil and the same amount of empty space, and have the flow of water agree closely, and this is the more difficult the heavier the soil is. If the soil is moistened before being loaded into the tube the rate of flow of water will be quicker up to a certain point with the amount of moisture the soil contained, showing that the grains had a different arrangement, and that the fine grains of clay were held more closely against the larger grains of sand.

The following results show this very plainly, the same kind of soil was used in all cases and contained about 26 per cent. of clay, the same tube was also used. Three hundred and fifty grams of soil were mixed with the requisite amount of moisture and loaded into the tube so that it should be 6 inches deep and contain 47.4 per cent. of empty space. The soil was then saturated and the rate of flow observed.

Grams.	Space.	Moisture.	Rate.
	Per cent.	*Per cent.*	*Minutes.*
350	47·4	0	128
350	47·4	2	65
350	47·4	3	60
350	47·4	4	45
350	47·4	6	36
350	47·4	8	27

There is a limit to this, of course, for when the soil contained too much water the grains were pushed out and the water went through much more slowly.

The rate of flow becomes much slower if the soil is left standing in the tube for a few days. Then, unless just the proper amount of empty space is left in the soil, the soil will either swell or contract when it is saturated with water. Even in the determinations of the flow in the soil in its natural condition in the field, if the sample is taken when the soil is dry it will often swell somewhat after it is imbedded in the paraffine and saturated with water.

These changes are extremely subtle and it is impossible, oftentimes, to detect any reason for the change. The addition of pure water or of fertilizing material may often change the rate of flow to a very remarkable extent. This whole work indicates that instead of being an inert mass the soil is extremely sensitive to all changes of conditions and is full of life and movement.

If these forces can be directed and controlled they are amply sufficient to bring about any desired change in the arrangement of the soil grains, and of the texture of the soil, and it remains to find out how these conditions can be most successfully controlled, or how best to take advantage of them in the improvement of the land.

A METHOD FOR THE DETERMINATION OF MOISTURE IN THE SOIL.

It is extremely desirable that a method be devised for the determination of the moisture in the soil, without removing a sample from the field.

A method which has given promise of good results is based on the changing electrical resistance between two plates, permanently buried in the soil, with the changing moisture content. But it seems to be impossible to secure good contact between the soil and the plates.

The method, as first devised, consisted of burying alternate plates of zinc and copper in the soil, and reading the deflections of a galvanometer when contact was made between the zinc and the copper plates. The deflections were far greater when the soil was wet than when it was dry, but polarization took place so rapidly that satisfactory readings could not be taken.

After this, copper plates were buried some distance apart and a current sent across from one to the other and the resistance measured, but this also was unsatisfactory. Finally an induction coil was used, and a Wheatstone bridge arrangement, with a telephone instead of a galvanometer. Copper plates were at first used to bury in the soil, then carbon, and lastly mercury, contained in clay or in flat porous cells such as is used in batteries.

The plates are put so far apart that the resistance is about 1,000 ohms when the soil is in "good condition" or contains about 8 or 10 per cent. of water. As the soil dries the resistance increases up to

1,500 or 2,000 ohms, and when it is saturated, after long continued rains, the resistance falls to about 200 ohms. The resistance regularly falls with increasing temperature, but the effect is far greater than for any known temperature coefficient.

When the plates are inclosed in sealed jars so that the water content remains constant, the resistance is constant for any temperature, even after the plates have remained undisturbed for a year or more. When the water content changes, however, the resistance gradually increases, so that when the soil is repeatedly wet and dried the resistance becomes much higher for any given condition of temperature and moisture.

It appears that the soil moves away from the surface of these foreign bodies. The soil presses against the plates with increasing temperature, and, the contact being better, the resistance is lower; as the temperature falls, however, the soil is withdrawn and the resistance rises. With changing moisture content the soil gradually compacts within itself and pulls away from the plates, and the resistance gradually increases.

In pot culture where the soil is contained in glass jars the soil becomes more compact and pulls away from the glass sides of the jar, leaving a considerable space between the soil and the sides of the jar. This is not so noticeable with porous earthenware pots, so it was thought that possibly the form or nature of the surface of the foreign body had something to do with this movement, and it was for this reason that carbon plates were substituted for copper. Such plates have been buried now for a year, and the resistance does not seem to have permanently increased, but every day the resistance rises and falls with changing temperature, as will be shown in the accompanying table.

It was thought that this movement might only occur at the surface of the foreign body, and it was attempted to imbed these carbon plates in clay and burn them in a porous tile. This could not readily be done, however, and then mercury was tried; first, by moulding a form of a plate in the soil, in moulding sand, or in clay, but much trouble was found in the liquid filtering down into the soil. The mercury was then put into flat, porous cells, and these were buried in the soil, but these also show the effect of changing temperature. As it has been shown in another way that the soil actually moves away from these foreign bodies and that this movement may continue for a long time, if the movement is followed up, it is evident that the mercury would give no better results if put directly in the soil than the carbon plates have given. There was this advantage in using the mercury instead of a rigid plate, that the mercury would follow the movement of the soil and maintain good contact. We have found, however, that with any yielding substance of this kind the movement would continue, and the indications are that the soil would contract or move away indefinitely from the foreign substance.

There seems to be no way to overcome this difficulty or to secure good contact with the soil, and it seems as though for this reason the method could not be perfected, but the indications it has given of this movement in the soil are of very great interest and value, and perhaps quite as important as the method itself would have been.

The accompanying table gives the readings for about three months of a series of carbon plates which were buried in the soil about a year before these readings were taken. There are three plates connected together on each side, each plate being 3 by 12 inches, and the two sets of plates were buried about 18 inches apart, the top of the plates being two inches below the surface of the ground. Rather more than the average amount of rain fell during this time and the soil has been unusually moist. During a prolonged drought the resistance of these plates would probably go up to 1,500 or 2,000 ohms.

Actual determinations have been made for part of the time of the amount of moisture in the soil, and the temperature of the soil as well as the principal meteorological conditions, but these are not given as they are hardly necessary in the present stage of the work. The important point to be worked out first is to secure the proper contact between the soil and plates and to overcome the extreme sensitiveness of this system to the natural movements within the soil.

Electrical resistance of the soil in ohms.

Date.	April.			May.			June.		
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.
1	....	....	....	280	260	305	165	170	220
2	....	....	....	330	315	355	227	227	285
3	....	....	....	345	335	380	270	245	280
4	....	....	....	400	355	337	285	255	265
5	....	....	....	387	365	440	250	255	200
6	....	....	....	462	407	377	200	220	255
7	....	....	....	417	395	500	270	255	270
8	....	....	....	535	450	530	265	200	158
9	....	....	....	....	450	520	160	....	....
10	....	....	....	605	485	499	140	140	145
11	....	....	....	300	260	245	155	150	180
12	510	430	510	255	255	301	180	160	200
13	595	470	539	309	280	325	200	200	200
14	595	560	350	320	310	....	255	235	265
15	310	265	265	185	180	150	290	....	....
16	320	270	325	160	155	185	300	295	295
17	300	285	300	200	190	210	335	315	285
18	270	257	240	245	220	225	295	275	....
19	255	200	250	220	160	155	270	270	300
20	260	250	244	170	150	167	300	....	260
21	220	220	220	160	160	....	290	280	300
22	220	200	200	160	....	165	315	305	330
23	210	195	210	170	160	182	....	180	200
24	200	190	205	200	175	203	220	215	....
25	235	225	245	220	195	234	150	....	175
26	250	220	267	245	225	175	200	200	230
27	285	245	300	155	150	165	220	220	135
28	330	315	340	175	149	160	135	135	149
29	315	265	250	175	170	175	150	150	151
30	265	220	270	175	160	150	178	125	....
31	....	....	....	155	160	165	....	....	....

A MOVEMENT OF SOIL GRAINS.

As it seemed probable from the variations in the electrical resistance of the soil that there was a movement of the soil grains this matter was made the subject of experimental investigation.

A thin rubber ice bag with a capacity of, approximately, 1,000 cubic centimeters, was securely fastened to a rubber stopper bearing a 60 cubic centimeter separating funnel for the admission of water, and a small tube, with an internal diameter of about 3 millimeters, which projected about 2 inches above the surface of the ground, and was then bent horizontally for about 18 inches in length, and was graduated the whole extent into eighths of an inch.

The rubber bag was about one-third filled with water and buried in the soil, the soil being pressed around the bag so as to force the water up into the small tube. The tube being horizontal maintained a constant pressure whether the bag expanded or contracted, and when the water fell in the tube, as it did almost every day, water was added through the separating funnel. This arrangement insured a constant pressure in the bag, and if there was any tendency for the soil to move away the bag would expand and follow it. The bag was buried in about 200 pounds of soil contained in a large tub and was kept in one corner of the laboratory in the house in Clifton, which is very solidly constructed. The soil was a mixture such as would be used in greenhouse work. There was no convenient way of determining the quantity of water in the soil, so it was watered from time to time and was kept in a fair condition for a growing plant.

This apparatus has been standing for nearly 4 months, and nearly every day water has to be added through the separating funnel to bring the level in the tube to the zero mark. It is set every morning, and, as a rule, the water gradually rises during the day and begins to fall in the afternoon and continues to fall during the night.

The movement is not constant, but seems to depend on meterological conditions. During a long rainy spell the water in the tube is generally beyond the zero point, and often during such periods it remains beyond the zero point for several days at a time; when the weather clears, and especially when there is a sudden change to clear, cold weather, the liquid falls in the tube very rapidly. Indeed, this movement is so extremely sensitive that it is frequently noticed that a change to stormy or fair weather could usually be depended on by the indications of this movement, often a day or two in advance of the actual change; that is, when the level of the liquid in the tube was over the zero mark persistently in fair weather, dull, rainy weather would nearly always follow within a day or two. On the other hand, in continued dull, rainy weather, with no apparent signs of clearing, the level of the liquid in the tube would very often begin to fall perhaps a day or two before the actual change occurred.

It was believed that these changes were dependent upon meteorological conditions, and there were indications both here and in the variation of the electrical resistance of the soil which seemed to show that this movement was largely dependent upon the changing atmospheric pressure as well, of course, as upon changing temperature. There seems to be no very simple relation, however, between the movement of the soil grains and the readings of the ordinary meteorological instruments, but still there does seem to be a relation between the movement of these soil grains and climatic changes.

One source of error which would hide any such close relation is in the extreme sensitiveness of the apparatus. At first, at any rate, before the soil became very compact in the tub, any one walking across the floor in the vicinity of the tub, or the least touch of a finger on the side of the tub, or a clap of thunder that would jar the tub, could be plainly recognized in their effect in the fall of the liquid in the tube. After the first few days the effect of this was hardly appreciable, but still it is impossible to say what effect they continued to have. A similar arrangement was buried in the soil of the field when this work was first started in South Carolina, but this was found also to be so extremely sensitive as to be affected by a footstep even a considerable distance away. The level of the liquid in the tube would rise and fall with the pressure of the foot on the ground.

When the apparatus was first set up the level of the liquid fell very rapidly whenever water was added to the soil, and it was believed that the repeated changes in moisture content was really the principal cause of the movement. As the soil became more compact, however, it was found that water could be added to the soil without materially affecting the level of the liquid in the tube. This was rather unexpected, as the movement still continued from other causes.

Fearing that the rubber sack which had been used in this instrument was rather thin, and that water was liable to get through the sides in one way or another, some other bags were made to order out of heavy, pure rubber cloth. The bags have a capacity of about 500 cubic centimeters, and were tested for several days, as was the other, in fact, before being set up. This apparatus was put into a very large, wide-mouthed glass packing bottle, and was put down in the basement, on a wide stone window-sill, where it was supposed it would be perfectly free from jar or disturbance of any kind, as the walls of the building are about two feet thick.

The jar is fitted with a manometer, and arranged so that the temperature or pressure can be varied at will, to study the effect of these conditions on the movement. The soil was put in air-dry, being pressed around the bag as before until the liquid rose into the tube.

The apparatus has been set up for very nearly two months, and the soil has not been watered during this time. The movement, however, goes on in this air-dry soil and the water is constantly falling in the tube as the soil compacts within itself and the bag expands. The level in the tube regularly rises every day above the zero point, and falls in the afternoon and night. But the total fall is greater than the rise, and water has to be added through the separating funnel to bring the liquid in the tube to the zero point. It must be remembered that the rise and fall of the water in the tube here referred to is not a vertical rise and fall which would vary the pressure, but is a horizontal flow, so that the pressure in the bag is constant.

This movement in the dry soil will be watched for a considerable time before water is added to the soil or the conditions are changed in any way, for it is a matter of very great interest. Similar apparatus will be planted out in the field, and the effect of stirring the soil or of cultivation will be studied.

This rubber bag, while flexible and adapting itself to marked changes of the soil, still can not follow any detailed movement as a growing root could, or develop in the line of greatest movement and of least resistance, but the whole side of a bag, or a large area, must move together, and this movement will depend upon the smallest movement of the soil grains. It seems certain, however, that the soil is moving away from these rubber bags, and the bags themselves, under a constant pressure from within, are slowly enlarging, and that the same forces that cause this movement may act in the development of roots through the soil, so that it would not be necessary to conceive of a root forcing its own way through the hard subsoil, as the soil itself will materially aid this development by a movement away from the surface of the root. This movement of the soil grains must have an important bearing on the development of roots through the soil, and the nature of the root surface and the matter which it exudes may have an important effect on the movement itself.

The accompanying table gives the readings of the apparatus in the soil in the tub for three months, with the temperature of the soil, and the very complete meteorological data for March from the records of the Weather Bureau observer in Baltimore. The meteorological instruments are located about 2½ miles in an air-line from Clifton, so that the results can not be as directly applied as though the observations were taken closer. The readings of the instrument are given in eighths of an inch, which was the graduation of the tube, and the last column gives the daily rise or fall in the tube in inches. The instrument was set at 8 a. m. each day by letting in water through the separating funnel to bring the water in the tube to the zero mark, but when the water was already beyond this point the instrument was not set.

Readings of the apparatus for three months.

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m. to 8 a. m.
March 1	59	....	....	0	....	− 1	− 1.37
2	60	62	59	− 5	− 3	....	− 1.00
3	59	60	....	−22	− 4	....	− 3.25
4	59	62	64	−17	− 6	−10	− 2.00
5	64	64	64	− 7	− 5	− 2	− 1.47
6	59	59	60	−78	+ 2	+ 2	− 12.00
7	57	60	62	−23	− 1	+11	− 2.90
8	61	62	64	+ 7	+ 3	+ 4	+ 0.87
9	62	64	65	−10	− 1	+ 1	− 2.12
10	63	65	66	−13	− 3	− 9	− 1.62
11	60	61	64	−71	− 1	− 2	− 8.87
12	57	60	62	−20	− 4	− 3	− 2.50
13	59	59	58	− 9	− 11	−24	− 1.12
14	57	58	58	−43	− 2	− 3	− 5.33
15	57	59	60	−16	0	+ 6	− 2.00
16	57	61	61	+23	+ 20	+19	+ 3.62
17	57	61	62	+10	+ 4	+12	− 1.62
18	55	58	56	− 1	− 14	*	− 1.37
19	55	58	59	....	....	−10	− 59.00
20	55	56	58	−78	+ 2	+ 2	− 12.00
21	55	58	59	−30	− 8	−15	− 3.75
22	53	59	61	−32	− 4	−10	− 4.00
23	59	62	65	+ 7	+ 5	+15	+ 0.85
24	61	63	64	− 7	− 7	+ 2	− 1.75
25	62	64	66	−13	−136*	− 1	− 1.62
26	62	63	64	−13	− 7	−26	− 18.36
27	62	62	61	−52	− 8	−27	− 6.50
28	58	61	64	−55	− 12	− 2	− 6.90
29	61	62	63	−17	− 5	− 4	− 2.13
30	60	63	66	−23	0	+11	− 2.87
31	62	64	64	− 9	− 5	−10	− 1.12
Mean	58.6	61	62	....	....	....	− 5.32
Total fall	....	....	....		(24.75 cc.)		−165.00

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m. to 8 a. m.
April 1	62	65	67	−26	− 1	0	− 3.25
2	66	67	68	− 1	−17*	−29	− 0.12
3	69	71	71	−38	+ 1	+11	− 4.75
4	71	71	71	+ 1	−17	−14	+ 1.25
5	70	70	71	−82	− 2	− 6	−10.25
6	70	70	67	−34	− 7	−13	− 4.25
7	66	68	67	−84	+ 3	+ 3	−10.50
8	64	66	66	−26	+ 1	+ 1	− 3.25
9	62	63	60	−20	− 7	−24	− 2.50
10	55	55	55	−55	− 6	−11	− 7.00
11	53	56	59	−68	− 1	+ 6	− 8.40
12	57	59	62	+10	+ 2	+10	+ 1.25
13	59	60	58	+ 7	+ 4	+ 4	+ 0.37
14	59	62	64	0*	0	− 1	− 0.87
15	58	61	61	−15	− 7	− 1	− 1.87
16	58	61	62	−23	− 1	+ 5	− 2.87
17	59	60	60	−12	0	0	− 1.50
18	58	62	67	−25	− 7	− 4	− 3.12
19	63	66	66	−17	− 1	+ 9	− 2.12
20	63	64	64	− 6	0	+ 3	− 0.75
21	63	64	64	− 7	− 3	− 5	− 0.93
22	61	64	65	−17	0	+ 4	− 2.12
23	63	68	65	− 4	− 1	+10	− 0.50
24	64	67	67	−12	+ 3	+11	− 1.50
25	64	65	64	− 5	− 6	− 5	− 0.62
26	62	63	63	−19	0	+ 2	− 2.37
27	60	63	65	−11	+ 1	+ 9	− 1.37
28	63	66	67	+12	+11	+18	+ 1.50
29	66	67	69	+19	+16	+15	+ 2.37
30	66	66	65	+ 1	− 1	0	− 2.25
Mean	62.4	64.3	64.6	....	....	....	− 2.35
Total fall	....	....	....		(10.58 cc.)		−70.59

*Added water to soil.

Readings of the apparatus for three months—Continued.

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a. m.	1 p.m.	8 p.m.	8 a. m.	1 p.m.	8 p.m.	8 a.m. to 8 a.m.
May 1	63	65	65	—16	0	+ 7	— 2.00
2	65	69	70	+ 3	+ 6	+17	+ 3.70
3	68	72	73	+13	+17	+19	+ 1.25
4	68	69	71	+18	— 5	+ 9	+ 0.62
5	68	69	69	— 1	— 3	— 8	— 2.12
6	67	69	71	—80	+ 4	+10	—10.00
7	67	68	65	— 7	— 5	— 4	— 0.87
8	62	63	62	—26	— 1	— 3	— 3.25
9	....	64	63	....	—20	+ 7	— 2.50
10	62	63	63	— 4	0	+ 4	— 0.50
11	63	65	66	— 4	— 2	+ 3	— 0.50
12	65	64	65	— 3	— 3	— 6	— 0.37
13	64	65	65	—20	+ 1	+ 8	— 2.50
14	63	64	....	— 7	— 4	....	— 0.87
15	64	65	66	—16	+ 3	+ 7	— 2.00
16	66	69	70	+ 9	—16	+25	+ 1.12
17	69	69	69	+21	+21	+26	+ 1.50
18	67	69	68	+18	+17	+19	— 0.27
19	68	69	68	+21	+21	+12	+ 0.27
20	66	68	60	0	+ 2	+ 6	— 2.62
21	64	65	....	— 6	— 9	....	— 0.75
22	62	....	61	—24	....	+ 3	— 3.00
23	62	63	62	— 3	+ 2	+ 4	— 0.27
24	62	63	63	0	— 1	+ 3	0.00
25	64	65	66	+ 2	+ 4	+10	+ 0.25
26	66	68	69	+12	+14	+22	+ 1.25
27	68	66	66	+18*	+26	+26	+ 0.75
28	63	63	63	+14	+14	+16	— 0.50
29	64	65	66	+ 2	+ 3	+ 1	— 1.50
30	66	68	70	—14	0	+ 2	— 2.00
31	69	71	72	—24	+ 1	0	— 3.00
Mean	65.1	66.5	66.4	....	....	....	— 0.97
Total fall	....	....	....		(4.54 cc.)		—30.28

* Added water to soil.

Meteorological data from the station at Baltimore for March, 1892.

Date.	Pressure.			Temperature.					Relative humidity.			Absolute humidity, grains per cubic foot.		
	8 a. m.	8 p. m.	Mean.	8 a. m.	8 p. m.	Max.	Min.	Mean.	8 a. m.	8 p. m.	Mean.	8 a. m.	8 p. m.	Mean.
	Inches.	*Inches.*	*Inches.*	°	°	°	°	°	*Pr.ct.*	*Pr.ct.*	*Pr.ct.*			
1	29.80	29.97	29.88	35.1	34.0	37	34	36	99	95	97	2.379	2.126	2.252
2	30.09	30.22	30.16	29.5	31.0	32	30	31	90	90	90	1.674	1.817	1.746
3	30.15	30.06	30.10	31.0	38.0	43	28	36	74	62	68	1.476	1.674	1.575
4	30.01	29.86	29.94	38.5	48.0	55	35	45	52	66	59	1.415	2.563	1.989
5	29.85	29.87	29.86	41.1	34.5	42	34	38	88	86	87	2.563	1.909	2.266
6	30.00	29.96	29.98	34.0	41.0	46	32	39	67	53	60	1.540	1.605	1.573
7	30.00	29.92	29.96	37.5	46.0	57	34	46	66	65	66	1.745	2.379	2.062
8	29.61	29.32	29.46	39.5	44.0	47	39	43	96	96	96	2.659	3.189	2.924
9	29.44	29.61	29.52	41.0	50.0	54	38	46	100	55	78	2.967	2.292	2.630
10	29.66	29.73	29.70	41.5	33.0	50	33	42	96	80	88	2.862	1.817	2.340
11	29.92	30.02	29.97	21.0	28.5	32	20	26	59	62	60	.806	1.138	.972
12	30.00	29.88	29.94	29.0	49.5	61	25	43	57	52	54	1.090	2.126	1.610
13	30.03	30.07	30.05	35.0	31.0	36	30	33	72	95	84	1.745	1.892	1.818
14	30.30	30.31	30.30	24.0	29.0	34	24	29	50	78	64	.772	1.470	1.124
15	30.41	30.34	30.38	25.9	33.5	35	25	30	53	58	55	.878	1.298	1.088
10	30.40	30.33	30.36	22.8	29.5	31	23	27	93	68	80	1.355	1.298	1.326
17	30.38	30.15	30.26	25.0	25.0	27	24	25	63	100	82	.999	1.606	1.302
18	29.82	29.69	29.76	27.3	30.0	31	24	28	89	84	86	1.540	1.605	1.573
19	29.91	29.90	29.90	24.1	34.5	39	23	31	62	58	60	.957	1.415	1.180
20	30.17	30.30	30.24	29.1	34.0	38	29	34	62	53	58	1.190	1.243	1.216
21	30.53	30.52	30.52	22.0	31.0	34	21	28	60	54	57	.841	1.090	.956
22	30.54	30.31	30.42	26.5	37.0	38	23	30	72	74	73	1.190	1.892	1.541
23	30.03	29.98	30.00	41.5	51.0	65	37	51	92	62	77	2.862	2.659	2.701
24	30.24	30.15	30.20	38.0	42.0	50	35	42	53	69	61	1.415	2.208	1.812
25	30.17	30.05	30.11	41.5	50.0	56	34	45	71	55	62	2.208	2.292	2.250
26	29.94	29.75	29.84	44.0	44.0	48	43	46	78	100	89	2.563	3.306	2.934
27	29.46	29.65	29.56	44.0	39.0	44	39	42	100	96	98	3.306	2.659	2.982
28	29.95	30.09	30.02	40.8	44.0	50	39	44	68	63	66	2.046	2.126	2.086
29	30.29	30.26	30.28	39.9	43.0	53	36	44	52	74	63	1.540	2.379	1.460
30	30.33	30.23	30.28	37.9	44.5	47	35	41	42	52	47	1.138	1.817	1.479
31	30.26	30.37	30.32	39.6	40.0	42	39	40	90	100	95	2.563	2.862	2.712

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

BULLETIN No. 5.

OBSERVATIONS AND EXPERIMENTS
ON THE
FLUCTUATIONS IN THE LEVEL AND RATE OF MOVEMENT
OF
GROUND-WATER
ON THE
WISCONSIN AGRICULTURAL EXPERIMENT STATION FARM
AND AT
WHITEWATER, WISCONSIN.

BY

FRANKLIN H. KING,
Professor of Agricultural Physics, University of Wisconsin;
Physicist, Wisconsin Agricultural Experiment Station.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
1892.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., August 15, 1892.

SIR: I have the honor to transmit herewith a report on "Observations and Experiments on the Fluctuations in the Level and Rate of Movement of Ground-Water on the Wisconsin Agricultural Experiment Station Farm and at Whitewater, Wis.," by Prof. F. H. King, of the University of Wisconsin, and to recommend its publication as Weather Bureau Bulletin No. 5. In this connection I would state that this is the third paper of a series on the relations of soils to meteorology, the object of which is to elicit information from specialists, rather than to indicate the views held by the Department on the subjects treated.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. J. M. RUSK,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

University of Wisconsin,
Agricultural Experiment Station,
Madison, Wis., August 12, 1892.

Sir: I have the honor to submit herewith a report on "Observations and Experiments on the Fluctuations in the Level and Rate of Movement of Ground-Water on the Wisconsin Agricultural Experiment Station Farm and at Whitewater, Wis."

F. H. King,
Professor of Agricultural Physics.

Mark W. Harrington,
Chief of Weather Bureau.

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OBSERVATIONS AND EXPERIMENTS ON THE FLUCTUATIONS IN THE LEVEL AND RATE OF MOVEMENT OF GROUND-WATER ON THE WISCONSIN AGRICULTURAL EXPERIMENT STATION FARM AND AT WHITEWATER, WISCONSIN.

FIRST OBSERVATIONS.

When the writer first became associated with the Wisconsin Agricultural Experiment Station in July, 1888, there existed upon the Station farm a double row of silt wells, twenty-four in number, connected with a system of drains. The ground immediately about these wells was seeded to blue grass, and the level of the ground-water had fallen below the level of the discharge pipes in many of these wells, but water still stood in them at distances varying from four to five feet below the surface of the ground. It occurred to the writer, in August of that year, that these wells might possibly furnish an occasion for ascertaining whether the diurnal variations in the rate of evaporation affected, to a measurable extent, through capillarity or root action, the rate of downward retreat of the ground-water surface. Accordingly a record of the height of the water surface in these wells, at 6 to 7 a. m. and 5 to 6 p. m., was kept during about two weeks, from which it appeared that there was a real diurnal change in the water-level, the water in most cases standing higher in the morning than on either the preceding or succeeding evening. That the water should be found lower on the evening following the morning was naturally anticipated on account of the general lowering of the water-surface by lateral drainage and the supposed possible lowering by upward flow through the capillarity of the soil and the pumping action of roots; but the general decided rise of the water in the majority of the wells during the night did not appear in accord with fluctuations due directly to the causes named. The surrounding topography and the distribution of vegetation over the surface, at the time the observations were being made, chanced to be such as to suggest that possibly the rise at night might be due to the large consumption of water during the daytime which resulted in depressing the level of ground-water in the locality of observation below the natural slope due to drainage, so that the rise during the night was due to hydrostatic pressure and lateral drainage from the surrounding higher lands or from lands where vegetation was, for the time being, making less demands upon the water in the soil. If this were the true explanation of the large fluctuations observed, it might be expected that those localities where most water was being consumed by vegetation would, other things being similar, show the largest diurnal fluctuations. To test this phase of the question, two other wells were dug, one in a field of growing corn 100 feet to the east of the line of wells in question and the other in a piece of oat stubble the same distance to the westward.

A comparison of the diurnal changes in the water-level of these wells proved that the fluctuations were unequal, being largest in the center of the corn, smallest in the oat stubble, where the least evaporation was to be expected, and intermediate in amount on the margin of the cornfield under the blue grass, which had been cut and was now short. The measured fluctuations, as they occurred in the three wells, are shown graphically in Fig. 1 for six consecutive days, beginning on the morning of September 8, 1888.

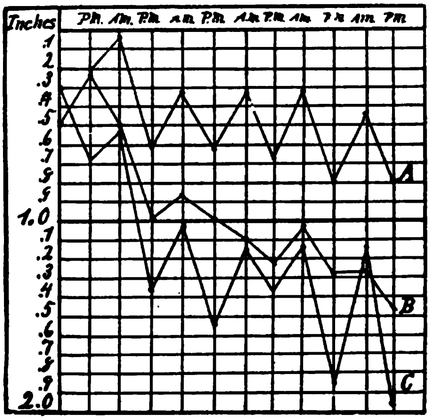

FIG. 1. Diurnal fluctuations in wells; *A*, on margin of cornfield; *B*, on oat stubble; *C*, in corn.

While these observations appeared to favor the view that the diurnal fluctuation of the water-level in these wells might be largely, if not wholly, due to a relatively rapid withdrawal of water from the soil by root action during the day, the fact that the water rose in the wells during the night to a height nearly equal to that which it had occupied on the morning of the previous day could not readily be accounted for by supposing that the water surface was warped downward by capillary and root action, because the magnitude of the diurnal changes demanded what would appear to be a much larger consumption of water during the day than the mean rate of lowering of the water-level appeared to warrant.

The observations which had been made up to this time showed conclusively that the fluctuations of the ground-water level were really very complex in their character and probably in their origin. It also appeared to the writer that if a ready and accurate means of keeping a record of the fluctuations of the level of standing water in the soil could be devised, new light might be thrown upon the percolation of rain water into soils of different types which lysimeters, from their necessarily limited areas and artificial character, cannot be expected to give. It was hoped also that such observations might be made to throw some light upon the distances below the surface different kinds of vegetation were able to utilize standing water in the ground.

In view of these and other considerations it was decided to dig a number of these wells in localities where the distance from the surface to standing water, the topography, the character of soil, and kinds of vegetation vary. Twenty-one wells were dug which, together with the 25 silt wells already in existence, made 46 in an area about 1,200 feet by 1,000 feet square. The wells varied in depth from 5 feet to 26 feet, and were made by boring with a 7-inch post auger provided with an extension handle. The wells were tubed with 5-inch drainage tile, surmounted, at the surface of the ground, with one length of 8-inch glazed sewer pipe provided with a galvanized iron cover controlled by lock and key.

INSTRUMENT FOR MEASURING CHANGES IN LEVEL OF WATER IN WELLS.

The instrument used in measuring the changes in the level of ground-water which we shall first consider is represented in Fig. 2, and consists of a chain with numbered links of uniform length, carrying, at its lower end, a heavy poise and provided with a micrometer at the other, graduated to read thousandths of an inch; this is mounted upon a base which can be placed upon the top of the well and attached to any desired link in the chain.

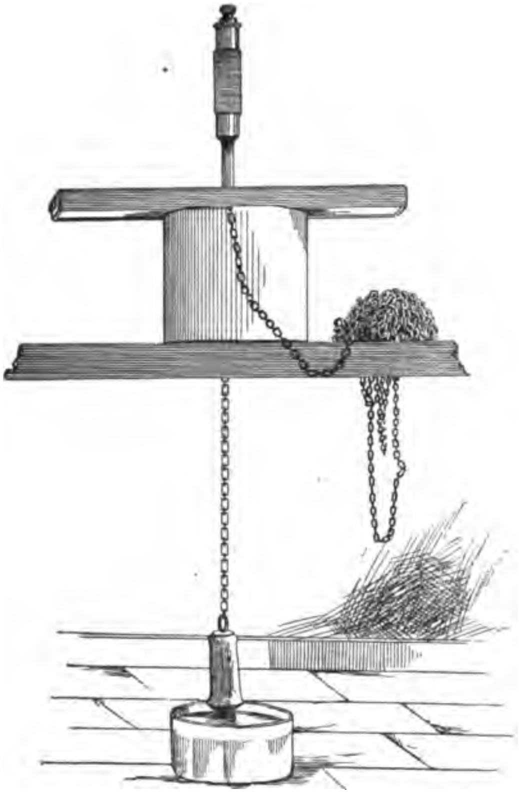

Fig. 2. Micrometer and chain for measuring changes in the level of water in wells.

The essential part of the poise is a hemispherical button of glass one inch in diameter which makes the contacts with the water surface. By lowering the poise gradually, until the button comes in contact with the water, surface tension, by drawing the water up on the button, develops waves on the water which, by their reflection of light, enable the moment of contact to be readily noted even in 6-inch wells 30 feet deep. Neither a plane nor a conical surface of contact develops such strong waves as does the hemispherical form.

The micrometer consists of a central spindle provided with a hook upon which the chain may be hung. This spindle is moved up or down by a hollow screw which slides over a core graduated to tenths of an inch, and the face of the screw is divided into 100 divisions, which enables distances of one-thousandths of an inch to be read off. With this instrument it has been found possible to measure with certainty changes of level in the water less than .03 of an inch.

TOPOGRAPHY OF THE AREA OCCUPIED BY THE WELLS.

The contour map, Fig. 3, will convey some idea of the differences of relief as they exist in the area under consideration. The hill shown in the center of the east side of the contour map rises to the eastward and attains a height of 111 feet above the lake, and then drops down to near the level of Lake Mendota about one mile to the eastward. To the southwest of the map the surface continues to rise nearly 80 feet higher and constitutes a long ridge lying parallel with the one above. The second hill, shown on the east margin of the map, is a small knoll not extending farther beyond the boundary of the area mapped than it does into it.

The exact position of all wells within the area under consideration is shown upon the contour map, where they are designated by numbers.

GEOLOGICAL STRUCTURE OF THE LOCALITY.

The experiment station farm, upon which the wells are located, lies just within the terminal moraine of the second glacial epoch, and the glacial till is laid down upon the very unevenly eroded surface of the Madison sandstone. All of the wells of series *A*, *B*, *C*, and *D* lie wholly in the till; wells 48, 49, 50, 51, and 53 pass through the till and penetrate the rock a few feet, while well 52 is said not to have reached rock at a depth of 84 feet, or 36 feet below lake level. Rock was reached in well 53, 16 feet below the lake, and 13 feet in well 48, but in wells 51 and 50 rock was reached 6 feet and 8 feet above the lake level, respectively.

The till is quite heterogeneous in its character, but is much more even at the level of ground-water than above. The whole area is mantled with a stratum of 2.5 feet to 4 feet of reddish clay containing pebbles and bowlders irregularly and generally sparsely distributed through it, the pebbles and bowlders being coarser and more numerous on the higher grounds. Beneath this mantle there is generally a rather rapid transition to a sand usually quite uniform and free from gravel everywhere below the 9-foot contour. Beneath the surface of higher levels the transition is into a coarse sandy and gravelly till containing stone 3 to 8 inches in diameter in considerable numbers but usually, before water is reached, the coarse materials are greatly decreased or entirely disappear and water is found in a sand of varying degrees of coarseness, it being, as a rule, decidedly finer than that under the lower grounds. Under the higher lands the sand below often approaches quicksand in fineness.

CONFIGURATION OF THE SURFACE OF THE GROUND-WATER.

The surface at which standing water is found in the ground is very far from being horizontal, as an inspection of Fig. 4 will show, where the contours are drawn to show the surface of standing water, as observed on June 20, 1892, at the 54 wells included in the area.

It will be observed, in the first place, that the level at which water stands in the wells is everywhere decidedly above the level of water in Lake Mendota, to which the contours are referred. Even in well 29, only 150 feet from the lake shore, the water on that date was found standing 7.2 feet above the lake level. In the well at Agricultural Hall, situated about 3,600 feet east of well 52 on the same ridge, but where the surface of the ground is 88 feet above the lake, the water in the ground stands 52 feet above the level of the lake, and this well is all the way in the till and not over 1,200 feet in a direct line from the shore and not much farther from land near lake level both to the southward and eastward.

A second point to be noted here is the general tendency of the water to stand at the highest level under the highest ground, but there are notable exceptions to this, and more at the particular date which the map represents than has been true at former times. Well 52, located upon the highest ground within the area, has yet the lowest recorded water-level excepting those within and near the tile-drained section shown in the map. This well, however, is a deep one encased in 84 feet of 6-inch iron tubing which is screw-coupled so as to be water-tight except at the bottom. Besides, it was in use during the whole winter, nearly all the water it could supply being taken from it until April 1. After the middle of April it was thrown entirely out of use and so continued until past the middle of May. At the time the measurement was taken the well was in use, but only a few pails of water were taken from it daily. Numbers 53 and 48 are also tubed wells, 52 and 40 feet deep respectively, but were not in use when the levels were taken. All other wells are comparable when account is taken of the fact that the drains, which were still discharging when the levels were taken, would tend to carry the ground-water to an abnormally low level in their immediate vicinity.

The real and marked exception to the general rule of the tendency of the ground-water to present a surface approaching conformability with that of the land above is found in well 39, where the water is 16.5 feet above the level of the lake, while that in well 38, less than 60 feet distant, is only half that amount.

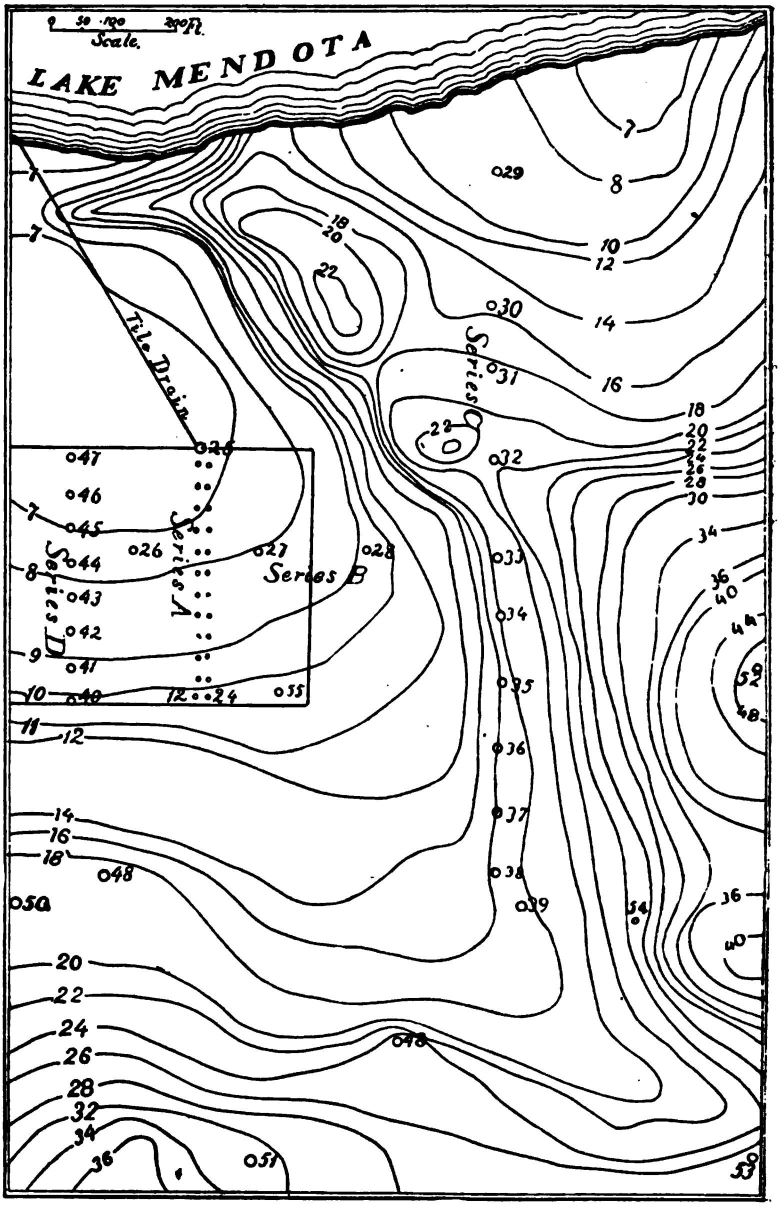

FIG. 3. Contour map of area occupied by wells. Figures in lines give height of contours above lake in feet; other figures indicate numbers of wells.

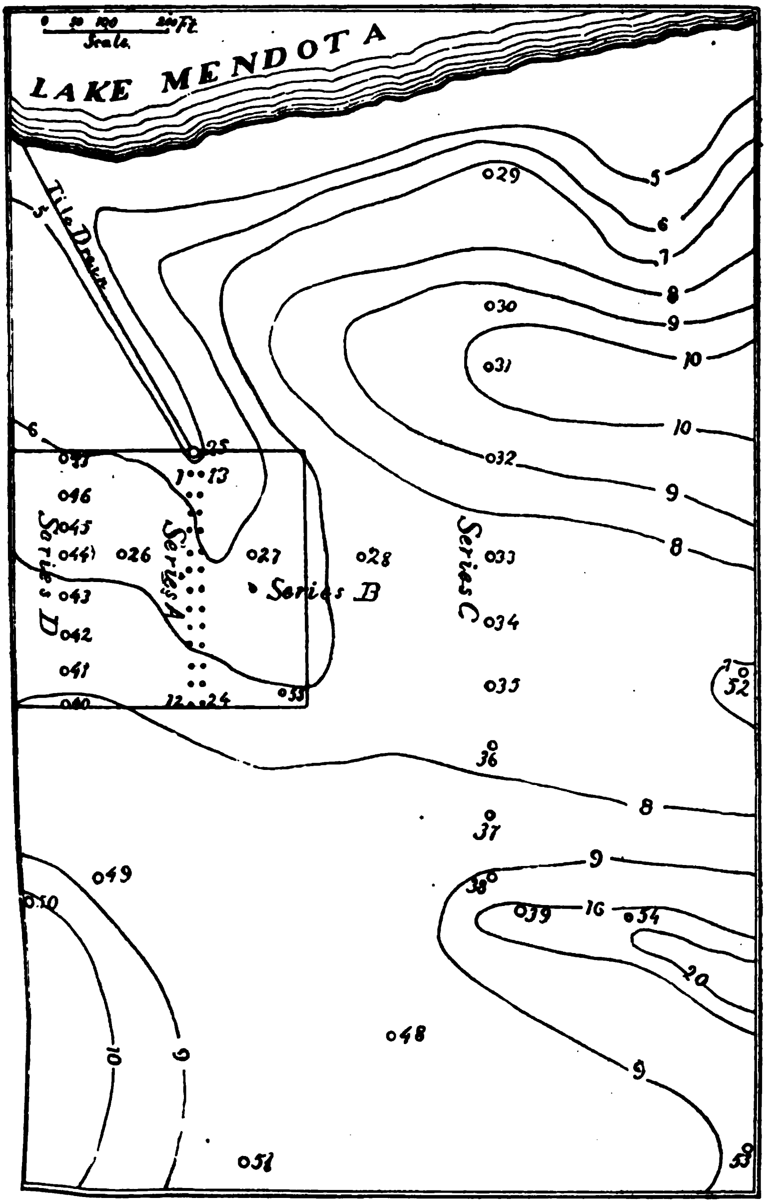

FIG. 4. Contour map of ground-water surface on June 20, 1892. Figures in lines give height of contours above lake in feet; other figures indicate numbers of wells.

The rise of the ground-water surface as it recedes from natural drainage outlets, and the resulting tendency to develop a surface unconformable with a true water-level, is not a local peculiarity, as has been pointed out by Baldwin Latham*, who expresses the fact as follows:

"The greatest elevation of the subterranean water is usually found under the highest lands, and the least elevation under the lands having the lowest levels. The flow of water laterally is from the hills to the valleys and longitudinally down the valley lines; therefore, as a general rule, the flow of subterranean water conforms to the surface of the country."

THE PERCOLATION OF WATER INTO WELLS.

The measured height of water in a well is not always a true index of the level of ground-water in that vicinity. If the well is in use and considerable quantities of water are being taken from it, the well becomes a drainage outlet toward which the water flows just as soon as the level of the water in it is depressed below that of the general level. The longer such a well is used, when percolation through the soil above does not equal the demand, the more the water-level is depressed below the normal and the wider the area of depressed water-level becomes. This causes the water which supplies the well to flow toward it down a continually decreasing slope, and at the same time through soil passageways of ever-increasing length and resistance. Under these conditions, it is evident that a well which is sunk but a few feet below the general level of ground-water would suffer a rapid decrease of capacity during dry seasons, whereas one which is sunk 15 to 20 feet below the natural water-level in the soil would make up in steepness of gradient for the increasing distance from which the water must move toward it from the surrounding soil, as an inspection of Fig. 5 will show.

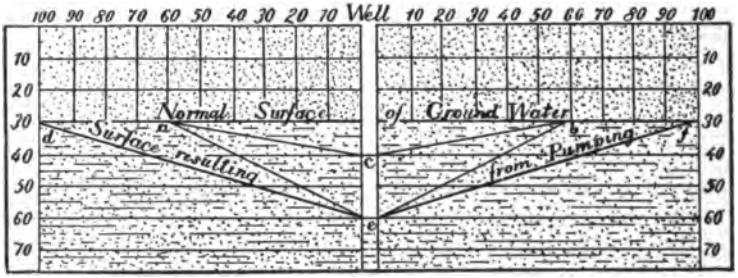

FIG. 5. Effect of pumping on the ground-water surface.

When the water in the well is lowered to 40 feet below the surface, as shown in the figure, and the water surface becomes depressed so

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* Report of British Association in 1877, page 207.

as to conform with the line *a b c*, there is a head or gradient of 1 in 6 tending to force the water into the well, but when the water is lowered to *c*, 30 feet below the general water-level, the gradient becomes 1 foot in 2; but even after long pumping, and the water-level becomes depressed so as to conform with the line *d e f*, the gradient is still steeper than in the first case, being 1 foot in 3 nearly.

It is evident, therefore, that in providing wells for farm stock there should be an ample depth below the normal level of standing water in the ground, and this must vary with the character of the soil or rock in which the water is stored and through which it must flow to enter the well, the depth required increasing, generally, with the degree of fineness of soil or rock because the resistance to flow increases with the smallness of the particles.

There are times when the height of water in wells is above that of the general level of ground-water in their immediate vicinity, and this occurs during wet seasons after protracted heavy rains and is more marked in clayey soils than in those more open, and more marked in shallow than in deep wells. In the percolation of rain water there is a general tendency for the water to flow laterally towards and accumulate in the wells. This effect is shown very clearly in Fig. 7, which represents the changes in the level of the water in wells, series *C*, whose positions are designated in the two contour maps, Figs. 3 and 4, pages 16 and 17.

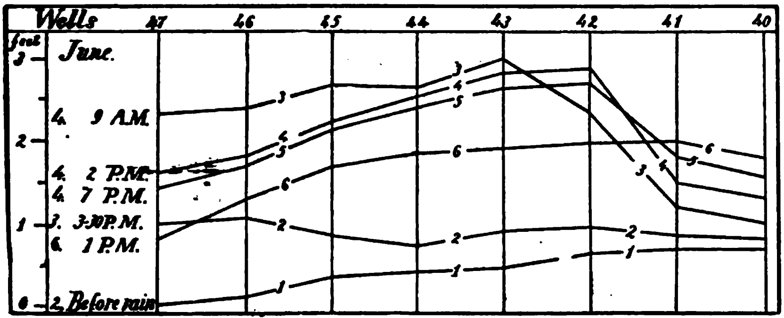

FIG. 6. Changes in the level of water in wells due to percolation.

These changes occurred after a rainfall of 3.19 inches, distributed in time as follows: June 2, 7.30 a. m. to 9 p. m., 1.38 inch; June 3, 7 a. m. to 2 p. m., .41 inch; 9 p. m., July 3, to 7 a. m., July 4, 1.18 inch; 9.15 p. m., July 4, and again 6.30 a. m., July 5, .22 inch.

It will be seen that a rainfall of 3.19 inches produced a rise of water in well 43 of about 2.5 feet, while in well 40 the rise did not exceed 1 foot. The greatest height of water in well 43 was reached on the morning of June 4, while the water in well 47 was still rising slightly 52 hours later, when the water in all the other wells had fallen from .9 foot in well 43 to 1.5 foot in well 47. It is true that the surface of the ground at well 40 is 3.3 feet higher than the surface at well 47, but the chief difference in the amount and rate of rise in the two wells is not due to this fact, neither is it due to water entering the wells at the immediate top, as will be seen from Fig. 7 and the observations stated in connection with it.

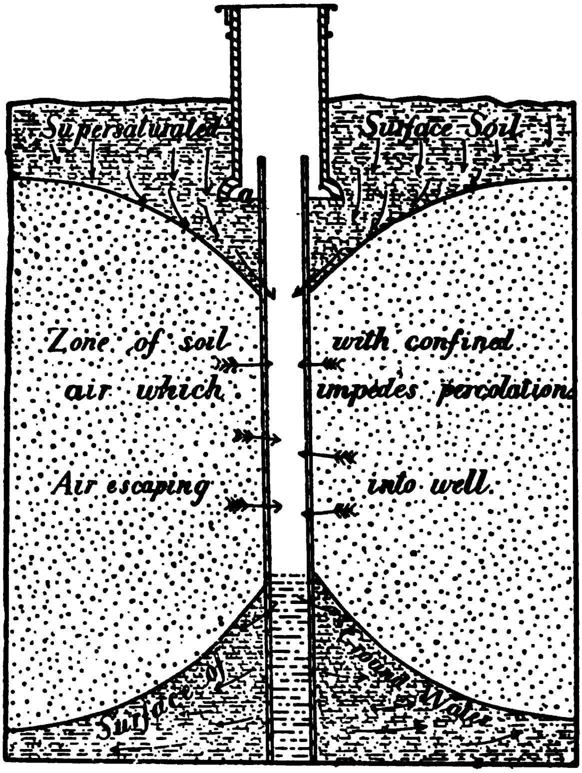

FIG. 7. Percolation of water into and out of wells.

All of the special wells used in these investigations are protected at the surface of the ground with a section of glazed tile provided with a lid, as shown in section in the cut, and it was repeatedly observed during times of rapid and excessive rises of water in the wells due to percolation that the surface of the soil at (*a*) remained dry during the whole interval of percolation, showing conclusively that the water did not enter the wells through the soil at the immediate surface.

The rise of water in wells above the general drainage surface during times of heavy rains is due to the inability of the soil-air to escape readily upward through the supersaturated surface, for so long as it can not escape it prevents the water from entering the soil spaces occupied by it; wells, however, which are not curbed with impervious tubing furnish an easy avenue of escape for the air, and it is forced out into the wells, allowing the water to follow it, so that there comes to be established, during times of percolation, a movement of water and air in the soil about a well something as represented by the arrows in Fig. 7.

In the sandy and more open soils, where the interspaces near the surface do not readily become closed with fine sediment moved by the water, there is not as great a lateral flow of water toward the wells, and the water does not rise in them very much more than the general water-level in the ground is raised during such times, and it is because the soil about wells 47 and 46 is much more sandy and open than it is about the others of this series that there is less rise of water in them at such times. That the lesser rate of rise and amount of it in wells 47 and 46 can not be due to the greater depth of soil through which the water is forced to penetrate is proven by the fact that while in well 28, where the distance from the surface to water at the time was very nearly the same as in well 47, the interval of time before percolation into it became evident was shorter and the amount of rise in it greater even than in well 40.

In trying to fill soil with water, in cylinders a foot in diameter, I have found it practically impossible to do so by adding water to the top, on account of the great difficulty of escape of air laterally or upward. In such cases it has been necessary to introduce the water through the bottom or else to put the soil into the water.

That fine textured soils do become almost impervious to air under moderate changes of pressure when they are saturated with water, even in the field under perfectly normal conditions, I have proven repeatedly with a piece of apparatus represented in Fig. 8.

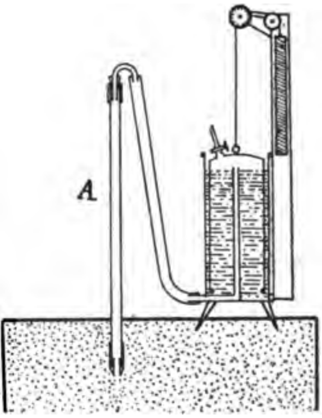

Fig. 8. Soil aspirator for studying the permeability of soil to air.

In using this apparatus the soil tube, *A*, was forced into the ground to near the desired depth at which the permeability to air was to be tested and then removed and the core of soil turned out. The tube was then returned to its place; and with an auger which would reach a fixed distance below the top of the soil tube, the hole was deepened; then by attaching the aspirator as shown in the figure a definite suction was established and the rate at which the air could be drawn through the soil into the aspirator determined. In this way it was shown that all the surface soils on the station farm are nearly impervious to air immediately after heavy rains and that all the clayey subsoils are completely so when they are nearly or quite saturated with water. These experiments, however, have not been performed under a greater reduction of pressure than one-tenth of an inch.

Referring now to the contour map of the surface of ground-water it will be observed that well 39, while on rather low ground, has the water standing in it at an abnormally high level, and this is due to the excessive percolation into the well during the present wet season. On the other hand, well 52, which is in the highest ground and yet with a very low water-level, represents the other phase which we have considered, a case where the ground-water has been lowered by excessive pumping.

A SANITARY PROBLEM.

There is a sanitary aspect of this question which should not be overlooked. Well 39 showed, by the rapid fall of a little more than 2 feet which took place in it during less than 10 days following the measurement recorded on the map, that its great height of water was due to lateral percolation into it, and the point to which I wish to direct attention is that we have here a ready means of ascertaining whether a well is subject to surface contamination or not. A sudden large rise and fall of the water-level in a well, associated with heavy rains, can have no other interpretation than that water reaches the well without being filtered through a very large amount of soil. An abrupt rise and fall of a few inches might have no significance here, as will be seen from observations recorded in another place, but where there is a rise and fall of a foot or more there can be no doubt but the well is liable to yield, at times, unsanitary water if the surface surroundings are such as to permit of it. The observations here recorded also indicate that wells located in clayey soils and subsoils may be much more subject to such surface contaminations than others in more open and porous ones.

Just how far it is practicable to protect wells which are subject to contamination in this manner, by using iron tubing or other similarly impervious curbing, is a matter which merits careful investigation, for it is a vital question in the building of country homes. It is generally taken for granted that wells thus constructed are safe against the infiltration of surface water, and it may be true to a large extent; but it does not appear improbable, in pumping water from a well tubed up with iron, that the rapid withdrawal of water from about the immediate terminus of the tubing would tend quite as strongly to bring the new supply of water directly downward from above as to induce it to come from below or from lateral directions, and if this is true, it is evident that the surface surroundings of a well used for domestic purposes should be scrupulously cared for even when provided with impervious curbing.

ONE CAUSE OF DECREASE OF HEAD IN ARTESIAN WELLS AND AT PUMPING STATIONS.

It is not an uncommon occurrence for artesian wells to show a decrease of head, which, in many cases, is very appreciable and not apparently caused by seasonal fluctuations of the level of ground-water, and the same fact has been observed at pumping stations also. In my judgment, the observations made in the preceding section offer a partial explanation of these changes; for the opening of an artesian well in an impervious soil through which water has not been discharging must have the effect of depressing the surface of the ground-water which contributes to the well, and as the new drainage surface of equilibrium must occupy a lower level it follows that the head must suffer a permanent decrease, and this might be such as to cause certain wells in a locality to cease flowing altogether.

SEASONAL CHANGES IN THE HEIGHT OF GROUND-WATER.

The impounding influence of all porous lands lying above drainage levels, causes the ground-water surface to rise during wet seasons while during dry ones it falls so that the effective head in artesian wells and in springs is increased or decreased periodically in accord with the fluctuations of the yearly rainfall and those other conditions which tend to diminish the amount of water which is able to enter the land. In the same manner, also, the capacity of ordinary wells to supply water varies as the general level of the ground-water rises and falls. The locality under consideration here is one in which the supply to shallow wells must be almost, if not quite, the percolation water of purely local rains.

The wells in series *C*, which are in the higher land of the station farm and most remote from the system of the drains, are best suited to show the long period fluctuations due to the quantitative relationship existing between the amount of rainfall and the rates of drainage and percolation. When the wells were sunk, in August, 1888, there was water in all of them except 31 and 36, and the level of the water in them is shown in Fig. 9, on a stated date in 1888, 1889, 1890, and 1892. During the latter part of the summers of 1889 to 1891, inclusive, all of the wells of this series became dry, except No. 30, which is nearest to the lake, and in each case it has been true that, after going dry, they did not contain water again until after April 1, the following spring.

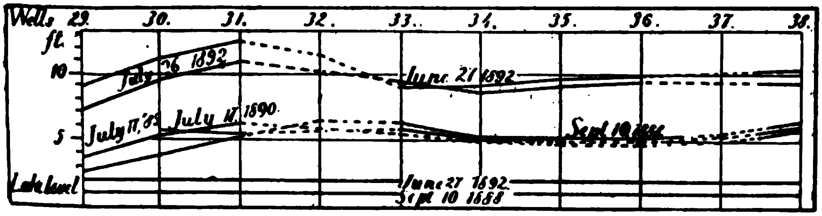

FIG. 9. Profiles of ground-water surface along the wells of series *C*.

It will be seen that the surface of ground-water in June, 1892, is from 4 to 5 feet higher than at any other season since the records began.

The level of Lake Mendota was also higher, but its range has been confined between this level and one almost two feet below.

RELATION BETWEEN THE AMOUNT OF RISE IN THE SURFACE OF GROUND-WATER AND THE RAINFALL.

When, in the spring of 1892, the surface of ground-water first began to rise above the level of the bottoms of the wells in series *C*, its contour had approached very close to horizontality, as shown in Fig. 10, where the profile lines of May 7 and May 21 show the configuration of the surface at those times. Between May 21 and June 7 the arithmetical mean rise for all of the measured wells was 1.5 foot, and the rainfall between those dates was 4.02 inches. Between June 7 and June 27 the mean rise was 2.38 feet, and the rainfall associated with it 4.97 inches. The total mean rise between May 21 and June 27 was 3.88 feet, and the rainfall for the same period 9.05 inches. During the first of these periods the water rose .373 foot for each inch of rain; in the second it rose .479 foot, and during the last, .428 foot for the same amount of rain.

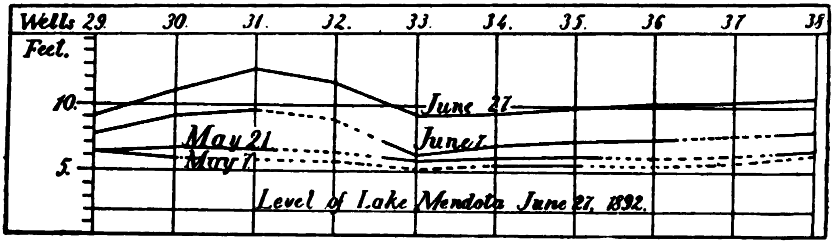

FIG. 10. Rise of the ground-water in relation to rainfall.

If we now refer to Fig. 6 and take the mean distance between the two lines 1 and 6 as representing the true rise of the ground-water surface due to percolation, we shall have for a rainfall of 3.19 inches a rise of 1.27 foot, or at the rate of .398 foot for each inch of rain. The general mean of all these is about .42 foot of rise in the ground-water for each inch of rain.

Determinations made at this station show that there is about .4 cubic foot of space in one cubic foot of dry sand, and that capillarily saturated sand standing one foot above water, such as the rise here considered took place in, would contain about 18 per cent. of its dry weight of water, while the weight of one cubic foot of such water-free soil is not far from 105 pounds. Under these quantitative relations the capillary water should occupy .32 cubic foot and the unoccupied space into which water could percolate would be only

$$1 \text{ cubic foot} - (.6 + .32) = .08 \text{ cubic foot},$$

or 138.24 cubic inches. Under these conditions an inch of rain should fill a cubic foot of soil more than full; but as the ground-water was raised at the mean rate of only about .42 foot it follows that either the soil did not contain 18 per cent. of its dry weight of water at the time the rains occurred or else that there was, during the time, a large amount of percolation through the zone under consideration.

THE CAPILLARY STORAGE CAPACITY OF LONG COLUMNS OF SOIL.

There is in my own mind no doubt that the soils considered in the last section, into which the water percolated, did not contain 18 per cent. of water at the time under consideration, and my reasons for this conviction are these: In coarse, sandy soils at least, if not in all others, the capillary holding power decreases in some undetermined ratio with the length of the column above standing water, as I have proven by the following experiment: Columns of medium grained plastering sand 42 inches long were constructed and suspended in a vertical position, as represented in Fig. 11. The sand for this experiment was stirred in water to expel all adhering air and then poured into the tubes through a funnel, sand and water together, the tubes being frequently shaken and jarred to insure a solid packing of the sand.

The tubes were hung in place on April 26, 1892, and percolation had not ceased on May 14, although the rate had become very small. At this time 20 cubic centimeters more water were poured into the tubes at the top, when a rapid percolation was set up immediately, but did not cease entirely until some time between June 3 and 10. On June 10 percolation had ceased, as shown by the receptacles having lost in weight .0237 grams to .0036 grams. The tubes were then cut into 6-inch sections, and the water content of the sand determined by placing the sections directly in the dry-oven. The tube which had been wet with distilled water possessed the distribution of capillary water indicated in Fig. 11, where it will be seen that there is a decreasing amount as the distance above standing water increases, it being 18.17 per cent. in the lower 6 inches and only 1.93 per cent. in the upper, with a mean of only 6.927 per cent. This difference in distribution was due wholly to percolation, as the nearly constant weight of the whole apparatus proved, that only showing an almost inappreciable loss through evaporation of water from the fine vents in the two corks at top and bottom.

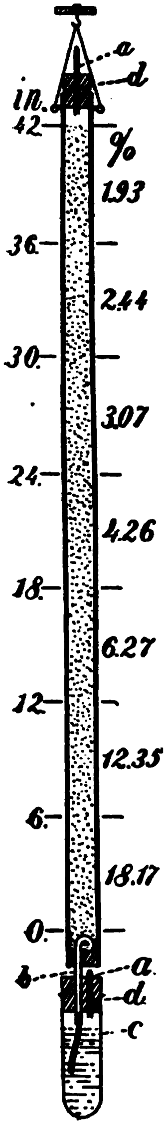

FIG. 11. Method of determining the distribution of capillary water in long columns of soil.

It was to me surprising that the percolation was so large and yet toward the close so extremely slow, but results of similar import have been obtained through direct observations upon soils in their natural positions in the field. In the Seventh Annual Report of this Station, page 144, a record is given of the change in the water content of the upper 5 feet of soil situated about 70 feet northwest of well 52, Fig. 3, which, during the interval from October 28, 1889, to April 14, 1890, was covered so as to exclude snow and rain, the object being to ascertain whether, during the winter, there was an increase of water in the soil through the aid of capillarity in drawing water up from below. It is there shown that instead of becoming more moist during the winter the water content actually decreased, and to the extent of 1.66 per cent. of the dry weight of the soil in the upper 4.5 feet; the lower 6 inches alone showing a gain in moisture. This loss of moisture referred to I then attributed to surface evaporation, "and possibly to lateral and downward translocation." Other observations now at hand, but which need not be detailed here, convince me that the chief loss of moisture in this soil during the winter was due to slow percolation downward, and that soils are drained more and more by percolation downward as the surface of ground-water recedes. Judging from the per cent. of water retained by the plastering sand it would appear that the zone of soil through which the ground-water rose during the interval from May 21 to June 27 may not, at the beginning, have contained more than 6 per cent. of the dry weight of the soil of water, and that it is due to this fact rather than to underground drainage that the surface of standing water in the ground was not carried to a greater height than was observed.

RELATION OF THE NORMAL GRADIENT OF THE GROUND-WATER SURFACE TO TILE DRAINAGE.

The prime function of tile drainage is to hold the surface of ground-water at an adequate depth so that there shall be ample room for root development, and as the ground-water rises with each increment of distance from the drainage outlet the proper distance to place the tile apart in a given soil, where they are to be placed at a stated depth, turns upon the resistance which the soil offers to the flow of water through it, for it is this resistance, just as in the flow of water through pipes, which determines, primarily, the steepness of the ground-water surface.

To determine the actual contour of the ground-water surface in a tile drained field when the drains were doing duty, a line of seven wells was sunk midway between the lines of tile which are laid in the area designated on the contour map, Fig. 3. The lines of tile in this field are laid as nearly as may be 33 feet apart and at a distance below the surface of the ground of about 4 feet. The wells referred to were put down midway between the lines of tile, and therefore were situated 16.5 feet from the drains on either side and at a distance not exceeding 30 feet from the line of silt wells into which the drains discharge.

The soil of this locality consists of 6 to 8 inches of medium clay loam followed by 2.5 to 3 feet of clay, below which is a stratum of rather coarse sand, in the upper surface of which the tiles are usually laid, and in spots this sand contains some gravel. The tiles are 3 inches inside diameter and laid on a grade of about 2 inches in 100 feet. At the time the levels were taken the tiles were discharging less than one-twentieth of their capacity.

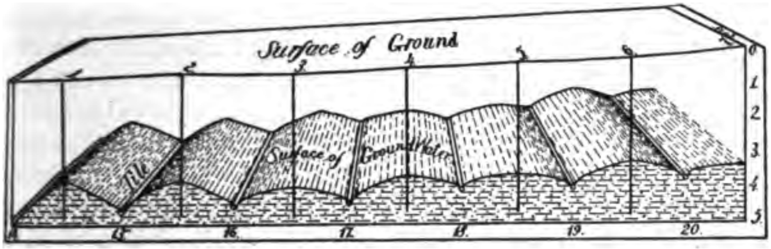

Fig. 12. Surface of ground-water between tile drains 48 hours after a rainfall of .87 inch.

The observed contour of ground-water in this field at 8 a. m., May 13, 48 hours after a rainfall of .87 inch, is represented in Fig. 12. The highest water-level in any well between these lines of tile on this date, when referred to the tops of the tile between which the wells are, was one foot in the case of well 1, above tile 14, and the least was about .3 foot in the case of well 5 above tile 18. Both wells 5 and 3 were sunk into a sand containing a considerable amount of gravel, and to this fact is probably due the less steep gradient at these places. Between well 2 and tile 16 two other wells were sunk, one two feet from the drain and the other midway between the drain and well 2. In the well 2 feet back from the drain water stood .3 foot above the top of the tile, and in the other, .45 foot above; the profile would present, therefore, a more or less curved contour, convex upward.

Assuming the water-level at the several lines of tile to be flush with the tops of the tile and regarding the water surface as presenting a right-line section, the mean gradient for the ground-water surface would be one foot in 25.38 feet. In well 29, 150 feet from the lake shore, the water stood 7.214 feet above the level of the lake on June 27, 1892, and this would give a gradient of one foot in 20.79. In the case of the well at Agricultural Hall to which I have referred as having a water-level 52 feet above the lake, and situated about 1,250 feet from the shore, the mean gradient would be one foot in 24.4. In the fall of 1888, September 10, when the water-level in the wells could not have been affected by lateral percolation into it, the gradient between well 29 and the lake was 1 foot in 35.86 feet.

In the tile drained area under consideration the configuration of the water surface did not remain as shown in Fig. 12, but changed as the water was carried away by the drains, and in Fig. 13 is shown the profile of the ground-water on these different dates. The changes which had occurred in the level of the water show that it was not drawn down at a uniform rate at all places, the surface falling fastest under the highest ground, where the water-level was also highest; also that the hydrostatic pressure of the water was there effective, tending to produce a horizontal movement from the upper toward lower portions of the tile drained area, associated with a downward vertical movement under the higher area, increasing the rate at which the level fell in that place and apparently decreasing it in the lower section by determining an upward tendency of the water from below.[*]

It is a constant feature in the discharge of water from this system of drains that those tiles laid in the lower ground continue to carry away water months after those under the. higher ground have ceased to do so, and as there is no more soil to hold water for the drains to carry away under the low than under the higher ground it follows that there is a tendency for the water to rise up into the zone affected by the lower tiles.

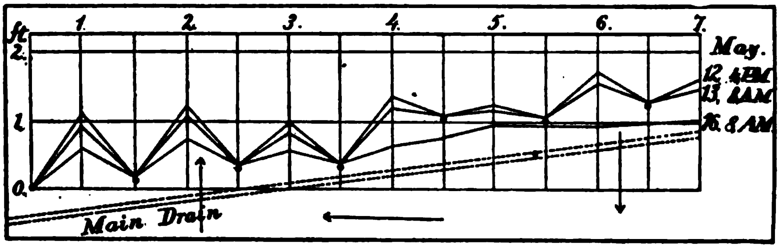

Fig. 13. Changes in level of water between tile drains.

NATURAL SUBIRRIGATION.

It is a fact long established by practical experience that many low lands which require tile draining in order to bring them under cultivation, and lying adjacent to higher areas, become, when so treated, if adequately done, the most productive lands of the locality, and while there are several conditions which render them so the paramount one is the water supply naturally provided by the upward tendency of it under the lower lands, coming from the supply of impounded water in the soil of the surrounding higher ground in the manner illustrated by the observed changes in the conformation of the ground-water surface referred to in the last section. The tile drains when properly placed serve during seasons of superabundance of water to hold the water-level below the zone of root action, while during seasons of deficient rainfall they do not interfere with its rise by hydrostatic pressure into the region where it becomes available to the growing crops. This is an important principle to understand in the selection of land for intensive farming.

Not all low lands adjacent to high areas are subject, in equal degree, to the natural subirrigation referred to, for geological differences of structure necessarily modify the movement of the rain which has entered the ground or may even prevent it from entering it so as to become available in the manner under consideration. The geological structure best adapted to the storing of water in the high lands and of giving it out gradually to the lower areas adjacent, is represented in Fig. 14, where the surface is mantled to a depth of 3 to 4 feet with clay soil and subsoil; this mantle on the high land passes by degrees through a porous, sandy and gravelly clay into a sand and gravel or pure sand of considerable depths into which the surface waters readily penetrate, and out of which they flow laterally with comparative ease. Under the hillside this coarse gravel and open storage material shades into a medium grained or rather fine sand through which the water can flow with some degree of freedom but not so rapidly as to fail to store the water to a considerable height above the surface of the low land. This type of geological structure is that possessed by the tract of land under special consideration here, and is very common throughout wide areas of the United States which are heavily mantled with the deposits of the later glacial epoch. The terminal moraines of this country are impounding reservoirs of great extent and capacity into which the rain sinks immediately and is there stored under conditions of least possible loss by evaporation, to be given out gradually in restricted but innumerable areas. Heavy rains which in differently constituted sections are lost to agriculture in disastrous floods are here safely and economically stored. It is to this stored water escaping slowly from the ground again, more than to direct rainfall and flat topography, that we owe the existence of our innumerable small lakes and the many acres of swamp and of lowland pastures so characteristic of glaciated areas, and it is to these many naturally subirrigated tracts which I wish to call attention, as being so promising for the purposes of market gardening and other types of intensive farming.

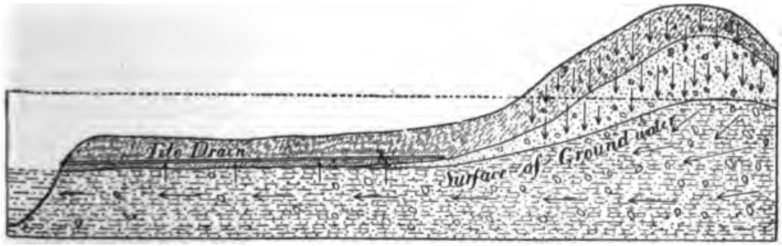

Fig. 14. Geological structure favorable to natural subirrigation.

There is another point in this connection to which attention should be called. There are numerous tracts of country underlaid by artesian waters, at varying depths, and where it is only necessary to penetrate the overlying impervious strata to obtain water at the surface. Now, it is a well established fact that the very best Portland cements are very far from being wholly impervious to water even under moderate pressures, and in view of this fact it has often occurred to me that a careful study of the yield of crops per acre for years of deficient rainfall, in artesian districts as compared with that of adjacent areas which are not, might reveal the fact that there is a not inconsiderable supply of water from below; which might help to explain the peculiar productiveness of certain sections.

This question is not without significance in its bearing upon the supply of water to cities, through the instrumentality of artesian wells, because if it is true that there is a slow but general drainage of artesian basins upward through the confining strata, one effect of this drainage might well be to develop an increasing porosity of the confining beds which would diminish the effective heads of the wells and might, in time, even cause them to cease to flow altogether, not from a diminished rainfall, but by a diversion to agricultural uses through a general subirrigation of the waters which had been or are being used for city purposes.

It does not appear impossible either, that in districts not underlaid by artesian waters, there might be a general lowering of the water in the wells of the higher grounds on account of an increasing porosity of the soils of the surrounding lower lands.

FLOW OF GROUND-WATER FROM THE LOWER UNDER THE HIGHER LANDS.

When a series of dry years have occurred, like the three just past, the surface of ground-water is drawn down to an abnormally low level, as was the case on May 7, shown in Fig. 10. Then when such a period is followed by heavy rains the soils of the low lands frequently become filled first so that the normal configuration of the water-surface is reversed, that under the low lands not infrequently standing higher than that under the higher areas. The reasons for this reversal are two, first, the low lands have less storage capacity than the high on account of there being less depth of soil, and second, not all the rains which fall upon the high lands can remain upon the surface long enough to enter the soil, and, as a result, the low lands not only receive practically the same amount of rainfall but a portion of that which falls upon the hills is carried, by surface drainage, down upon them, and in this manner the ground-water level may be carried several feet above that under adjacent higher lands. Referring to Figs. 9 and 10, and to the two contour maps, Figs. 3 and 4, it will be seen that in September, 1888, the water-level at well 33 is higher than at any other point, whereas on June 27, 1892, the water there has a lower level than at any other point along that line of wells. Under these conditions there is a reversal of the direction of the underground movement of the soil water, the current setting from
areas toward the higher lands, and by this reversal there is
o the high lands a portion of the water which fell upon

them as rain after it had flowed down upon and percolated into the bordering lower grounds. Well 33 has been, and is at this date, July 18, still rising, while the water in the other wells is falling.

THE RATE AT WHICH THE LEVEL OF THE GROUND-WATER SURFACE CHANGES.

The mean rate at which the ground-water surface rises and falls has varied between rather wide limits, but, as a general rule, a much shorter period has been required to produce a given rise than has been consumed in producing an equal change downward.

In Plate I, I have plotted the twice-daily observations on wells of Series *B* and *D*, extending over 100 days beginning June 8, 1889, and ending September 17. At the beginning of these observations the surface of the ground-water was already below the level of most of the tiles so that the lowering of the surface could not be influenced directly by the action of the drains. The total mean fall of the ground-water surface for wells 40 to 46 and 27 and 28 was 13.95 inches during the 80 days from June 18 to September 6, or a mean daily rate of .174 inch. During 131 days, from May 27 to October 29, the total mean fall was 20.495 inches, with a mean daily rate of .156 inch for wells 40 to 46. During 112 days, from June 9 to October 7, 1890, the total mean fall for the same wells was 20.086 inches, or a mean daily rate of .179 inch.

An inspection of the chart shows that the different wells did not all fall at a uniform rate, and if we arrange them in the order of the distance of standing water in the ground below the surface we shall have—

	Inches.
Well 46 fell during 80 days	13. 2
Well 27 fell during 80 days	12. 1
Well 45 fell during 80 days	12. 9
Well 44 fell during 80 days	13. 25
Well 28 fell during 80 days	13. 8
Well 43 fell during 80 days	18. 8
Well 42 fell during 80 days	15. 0
Well 41 fell during 80 days	15. 4
Well 40 fell during 80 days	16. 6

With but one exception, that of well 45 as compared with 46, the water fell more rapidly in the shallow than in the deep wells. The more rapid fall of the ground-water under the lower land was due to two causes, first, the shorter distance to the drainage outlet at the lake making the resistance to the flow less, and, second, to a more rapid loss of water at the surface of the ground through combined capillary and root action.

To ascertain whether corn exerts a measurable influence in depressing the ground-water surface, the ground occupied by the wells of series *D* was divided transversely into as many plots as there are wells, and in 1889 corn was planted over wells 40, 42, 44, and 46, while the ground about wells 41, 43, 45, and 47 was left fallow; then in 1890 the conditions were reversed. Determining the mean fall of the water on the fallow plots and comparing this with the mean fall observed on the corn plots for the two years, we get the results given in the table below:

Table showing mean fall of water on corn ground compared with that on the fallow ground.

Date.	Corn.	Fallow.	Difference.
1889.	*Inches.*	*Inches.*	*Inch.*
May 27 to June 20	1.973	1.918	.055
May 27 to July 1	3.516	3.156	.360
May 27 to July 10	5.442	5.091	.351
May 27 to August 1	8.585	8.353	.232
May 27 to August 24	12.088	11.978	.110
May 27 to September 26	15.443	15.324	.119
May 27 to October 29	20.573	20.416	.157
1890.			
June 19 to July 2	2.914	2.646	.268
June 19 to July 10	7.248	6.965	.283
June 19 to August 1	13.532	13.359	.173
June 19 to August 28	17.456	17.052	.404
June 19 to September 27	19.872	19.485	.387
June 19 to October 7	20.288	19.884	.404

It will be here seen that during the whole of the growing season the mean fall of the water under the corn plots was greater than it was under the fallow ones, not simply in 1889, but also in 1890, when the plots were reversed. It would appear, therefore, so far as two concordant trials can prove a complex problem, of this character, that corn does exert a measurable influence in depressing the surface of standing water in the ground where it lies at the distance below the surface which it occupied in these trials, which was 7.77 feet at well 40 in 1889, on September 26, when the corn was cut. During the season of 1890, after the June rains, the water was raised about 1 foot above the level of the preceding year at this date, and this difference was maintained throughout the growing season, and associated with this higher level of the ground-water there was a larger difference between the levels of the water under the fallow plots and those bearing corn, a feature which should be expected if an increase of vertical distance diminishes the rate at which water can be moved toward the surface.

The abrupt rise of the water in all of the wells shown on the left margin of Plate I was due to direct percolation of water following the rainfall of a little more than 1.1 inch shown at the foot of the plate. Examining these rises in detail, it will be seen that the two shallowest wells, Nos. 5 and 41, responded at once, while the others lagged behind varying lengths of time, the highest point not being reached in the deepest wells, Nos. 46, 45, and 28, until after the lapse of 48 to 72 hours after the rain began. It will be noticed, also, that wells 46 and 45, which are in the more sandy soil, show only the general rise of the whole ground-water surface, while all the others show by the abrupt fall of the water that there had been a lateral percolation of water into them.

There are other long period and nearly synchronous rises shown by the curves which are common to all of the wells, but which do not appear to be so plainly the direct result of percolation, although all of them occur near or at the time of rainfalls of greater or less amounts. These are six in number, the last one being double; the first occurs after July 2, following a rainfall of about .5 inch, but is of small magnitude; the second is larger and follows a similar rain which fell on the 14th; the third, a very marked one, following the rains of the 26th to the 29th, but the culminating point is not reached until August 2, where there is another rain of .05 inch, and six days later than the main fall of rain; following August 8, the fourth occurs after a rain of about .5 inch; the fifth is very slight except in well 27, and occurs two days later than a rainfall of .12 inch; while the last and most pronounced rise of all except the one first referred to attains its summit five days after a rainfall of 1.3 inch.

The surface soil had become very dry just before all of these rains, crops were suffering for water badly, and no one of the drains showed signs of discharging, whereas after the first period of rise they did. It does not appear to me, therefore, that these can be cases of rise in the ground-water due to percolation from the surface.

If these are in reality not cases of direct percolation, such fluctuations might be accounted for in this particular locality by supposing that the higher ground, which the map shows to lie between the area under consideration and the lake, retards surface evaporation, as would be the case on other surrounding high lands, while the lower tract, where the wells are located, lying closer to standing water in the ground might permit a more rapid lowering of the water surface by the greater effect of evaporation being added to that of drainage so that the level became here depressed below the level normal to the drainage resistance. If this had really occurred, any cause which would diminish the rate of upward movement of water to the surface from the ground-water surface would permit the level to rise toward the normal drainage level, and thus develop the fluctuations noted. A really serious objection to this view is found in the fact that wetting the surface of soil under certain conditions of dryness induces a more rapid movement of water toward the surface from below, sometimes through depths as great as four feet, as direct observations have shown. There is, however, no evidence presented by the character of the curves under consideration that such an increased movement has developed a more rapid fall of the ground-water as should be true if the influence in question extended to that depth.

But the most remarkable peculiarity presented by these curves is the pronounced, and in some cases extremely large, diurnal fluctuations in the level of water in these wells. The curves show that there is a general tendency for the water either to rise during the night or else to fall less rapidly than during the day, and these will be referred to again.

RELATION OF THE RATE OF FALL IN THE GROUND-WATER SURFACE TO BAROMETRIC PRESSURE.

To ascertain whether there is a difference in the mean rate of fall of the ground-water surface, when judged by well measurements, the data obtained through the use of the micrometer have been tabulated in such a manner as to show the amount of change in the water-level during the interval from highest barometer to the following lowest pressure, which is not less than .1 inch lower, and this has been compared with the change which was found to occur during the following interval of barometric rise to the highest point, which was not less than .1 inch higher.

To render the amounts of change during the different periods comparable, the mean daily rate of change has been determined by dividing the total change observed in each period by the number of days in them. Since rainy periods are associated with times of low barometric pressure, whatever percolation may have occurred during periods of falling barometer would tend to diminish the normal fall of water for times of low pressure, and at the same time tend to increase the fall during periods of high pressure, except at times of large rainfall, which caused the period of percolation to extend into or across one or more periods of high pressure.

Table showing mean daily rate of change in the ground-water level associated with rising and falling barometer.

Period.	Date.	Rainfall.	Changes.			
			Barometer rising.		Barometer falling.	
			Barometer.	Wells.	Wells.	Barometer.
	1888.	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inch.*
1	September 18-23	.24	+.59	— .121		
2	September 23-25	.04			+ .116	—.73
3	September 25-29		.74	— .212		
4	September 29-October 1				+ .153	.85
5	October 1-2		.63	— .895		
6	October 2-3		.61	— .441		
7	October 3-4				+ .096	.34
8	October 4-6		.33	— .192		
9	October 9-13				— .045	.27
10	October 13-14		.19	— .233		
11	October 14-16	.13			+ .077	.22
12	October 16-18	.76	.35	— .103		
13	October 18-19				+ .640	.31
14	October 19-21		.52	— .184		
15	October 21-27	.79			+ .046	.60
16	October 27-30		.42	— .129		
17	October 30-31				+ .243	.34
18	October 31-November 1		.10	— .247		
19	November 1-2	.05			+ .307	.19

Table showing mean daily rate of change in the ground-water level—Continued.

Period.	Date.	Rainfall.	Changes.			
			Barometer rising.		Barometer falling.	
			Barometer.	Wells.	Wells.	Barometer.
	1888.	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inch.*
20	November 2-3	·41	·31	− ·123		
21	November 3-5				+ ·043	·22
22	November 5-7	·17	·31	− ·130		
23	November 7-10	·58			+ ·236	·50
24	November 16-20		·51	− ·149		
25	November 20-23				− ·045	·28
26	December 3-5				− ·078	·44
27	December 5-6		·53	− ·240		
28	December 6-7				+ ·180	·29
29	December 11-14		·35	− ·130		
	1889.					
30	May 3-7				− ·103	·60
31	May 7-9	·30	·34	− ·274		
32	May 9-10	·15			+ ·045	·11
33	May 10-11		·12	− ·233		
34	May 11-16	·44			− ·062	·23
35	May 16-22	1·01	·34	− ·115		
36	May 22-23				+ ·045	·23
37	May 23-25	·09	·22	− ·210		
38	May 25-27	1·02			+ ·398	·38
39	May 27-30		·39	− ·245		
40	May 30-June 3	·04			− ·016	·33
41	June 3-6		·16	− ·182		
42	June 6-7	·07			+ ·001	·29
43	June 7-10	·58	·45	− ·037		
44	June 10-15				− ·153	·07
45	June 15-19	1·14			+ ·211	·37
46	June 19-24	·10	·68	− ·296		
47	June 24-26				− ·149	·31
48	July 3-6	·23	·33	− ·173		
49	July 6-9				− ·305	·25
50	July 9-11		·16	− ·233		
51	July 11-12				− ·353	·24
52	July 12-16	·49	·28	− ·072		
53	July 16-18				− ·148	·43
54	July 18-24		·37	− ·214		
55	July 24-28	·83			− ·080	·38
56	July 28-31	·29	·48	− ·036		
57	July 31-August 1				− ·084	·22
58	August 1-6	·05	·30	− ·165		
59	August 6-8				− ·199	·28
60	August 8-11	·50	·20	− ·017		
61	August 11-13				− ·139	·30
62	August 13-17	·05	·24	− ·129		
63	August 17-20				− ·220	·28
64	August 20-26	·12	·34	− ·197		
65	August 26-28				− ·216	·12
66	August 28-31		·17	− ·242		
67	August 31-September 4	·03			− ·169	·47
68	September 4-11	1·44	·43	+ ·204		
69	September 11-14				− ·102	·31
70	September 14-16	·23	·25	− ·114		
71	September 18-20				− ·074	·48
72	September 20-22		·44	− ·184		
73	September 22-23				− ·060	·25
74	September 23-27	·09	·47	− ·101		
75	September 27-30	·14			− ·040	·53
76	September 30-October 2		·39	− ·142		
77	October 2-3				− ·126	·18
78	October 3-4		·37	− ·215		
79	October 4-5				− ·099	·24
80	October 12-14		·56	− ·104		
81	October 14-19				− ·030	·60
82	October 19-23		·58	− ·060		
83	October 23-25				+ ·106	·80
84	October 25-29		·48	− ·070		
85	October 29-November 2	·31			+ ·097	·62
86	November 2-5	·03	·95	− ·147		
87	November 5-13	·07			+ ·110	·67
	1890.					
88	June 2-5	2·97			+7·162	·32
89	June 5-9	·22	·51	−2·931		
90	June 14-16	1·76	·23	+5·340		
*96	June 19-21	·83			+2·105	·24
97	June 21-23	·38	·13	+ ·138		

*Some periods in the original tables are omitted here.

Table showing mean daily rate of change in the ground-water level—Continued.

Period.	Date.	Rainfall.	Changes.			
			Barometer rising.		Barometer falling.	
			Barometer.	Wells.	Wells.	Barometer.
	1890.	*Inches.*	*Inch.*	*Inches.*	*Inches.*	*Inch.*
98	June 23-24				− .932	.10
99	June 24-26	.48	.12	− .302		
100	June 26-July 1	.025			− .724	.24
101	July 1-5	.11	.31	− .545		
102	July 5-7	.11			− .289	.24
103	July 7-10		.36	− .549		
104	July 10-14				− .196	.39
105	July 14-16	.10	.41	− .354		
106	July 16-17				− .216	.26
107	July 17-19	.09	.24	− .407		
108	July 21-24	.475			− .201	.45
109	August 1-3				− .284	.14
110	August 3-6	1.505	.21	− .106		
111	August 6-8				− .122	.39
112	August 8-11		.46	− .332		
113	August 11-13				− .046	.21
114	August 13-15		.17	− .361		
115	August 15-16	.15			+ .004	.15
116	August 16-18	.96	.19	− .065		
117	August 18-19	.10			+ .055	.23
118	August 19-20		.15	− .207		
119	August 20-21	.05			− .001	.23
120	August 21-23	.06	.40	− .338		
121	August 23-26	1.35			+ .218	.52
122	August 26-30	.06	.32	− .235		
	1891.					
123	April 8-10				+2.456	.54
124	April 10-12		.41	+1.270		
125	April 12-14	.18			− .127	.31
126	April 14-16	.30	.42	+ .593		
127	April 16-18				+ .328	.32
128	April 18-20		.24	− .505		
129	April 20-23	.52			+1.013	.30
130	April 23-24		.17	− .681		
131	April 27-28	.23	.30	− .990		

If we compare the changes in water-level which occurred during the two long intervals in 1888, when there was no rain, and the long one in 1889 at times of rising and falling barometer we shall have, for the mean daily change, the following results:

	Rising barometer.	Falling barometer.
	Inch.	*Inch.*
Periods 3 to 10	− .395	+ .068
Periods 24 to 29	− .173	+ .019
Periods 76 to 84	− .118	− .037
General mean	− .229	+ .017

For these intervals of time, therefore, there was a mean daily fall of the water-surface during the days of rising barometer amounting to .229 inch, while during the periods of falling barometer there was a mean daily rise of .017 inch.

If we determine the mean daily change during all the periods of rising barometer in 1888 and in 1889, and in those of 1890, after the heavy rains preceding July 5, and compare these with that which occurred during the periods of falling barometer for the same intervals of time, we shall have the results given below:

Mean daily change for—	Rising barometer.	Falling barometer.
	Inch.	*Inch.*
1888	— .235	+ .141
1889	— .143	— .046
1890	— .295	— .098
General mean	— .224	— .001

These observations show that a generalized curve representing the fall of water in a well would have a form such that the steeper slopes span intervals of rising barometer and the less steep ones periods of falling barometer.

RATE OF CHANGE IN THE GROUND-WATER LEVEL FROM MORNING TO EVENING AND FROM EVENING TO MORNING.

As has already been pointed out, there is a general tendency for the water-level of the wells under consideration to fall more rapidly during the day than during the night, and it is proposed, in the following tables, to give some of the data upon which the above statement is founded. The observations for the several wells have been grouped into periods and the total change which occurred from morning to evening and again from evening to morning for each of these periods determined. To reduce these all to a common unit, the observed total change for each well during a given period has been treated as follows:

Let a = total observed change in well during a given period;
b = length of time, in hours, between the a. m. and p. m., or p. m. and a. m. observations;
n = number of observations in the period.

Then, $\frac{a}{b\,n} \cdot 1{,}000$ = change for 1,000 hours.

This is supposing the observed mean rate to have continued during 1,000 hours. The following table contains the results of this treatment for the wells there specified by Arabic numerals at the left during the periods numbered in Roman at the top:

Table showing changes in the level of ground-water from morning to evening and from evening to morning, computed for 1,000 hours.

Number of well.	Period I.		Period II.		Period III.		Period IV.		Period V.	
	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.
26	−12.632	− 1.128	− 8.259	− 5.266	+3.158	− 2.228	+1.749	+ 2.517	−6.551	+2.586
27	−14.211	+ 1.505	+ .486	−11.285	+2.915	− 5.517	− .486	+ 1.379	−2.936	−2.351
28	− 2.297	− 8.276	+ 1.943	−13.166	+7.288	−10.000	+3.887	− 1.379	−2.232	−2.351
5	....	....	−12.105	+ 4.966	−4.050	+ 2.228	+ .194	+ .552	−8.808	+5.408
13	− 9.473	+ 3.009	− 6.073	+ 1.316	− .486	− 1.379	−1.263	− 1.931	....	....
14	−12.634	+ .460	....	....	....	....	....	....	....	....
15	− 9.473	+ .758	− 5.830	.000	− .541	+ .700	+1.069	− 1.103	....	....
16	−10.526	+ 3.762	− 3.887	− 1.505	−2.707	+ 2.228	− .094	+ .759	....	....
17	−15.789	+ 5.642	....	....	....	....	....	....	....	....
6	−25.263	+ 8.276	−15.304	+ .564	−4.060	+ 1.910	−3.401	+ 3.793	....	....
7	−28.431	+11.285	....	....	....	....	....	....	....	....
39	−41.474	+12.260	− 5.831	−28.589	+8.745	+ 6.207	+2.818	+12.483	....	....
Average	−16.655	+ 3.390	− 6.096	− 5.885	+1.594	− .750	+ .519	+ 1.897	−5.132	+8.23

Number of well.	Period VI.		Period VII.		Period VIII.		Period IX.	
	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.
26	−11.539	+ 9.962	−15.351	− 1.069	−11.348	− 9.665	− 8.862	− .271
27	− .976	− 1.097	−10.526	− 4.774	− 3.691	−13.163	− 5.215	− 4.655
28	− 1.144	− 1.628	− 5.012	−10.688	− 3.445	−10.757	− 4.373	− 7.857
5	−10.086	+10.934	−15.915	+ 3.527	−21.821	− 4.634	−91.452	+86.593
40	− 4.541	− 1.593	− 7.205	− 8.194	− 2.969	−10.834	− 5.028	− 7.090
41	− 2.725	− 2.442	− 8.145	− 6.769	− 6.582	− 7.278	− 5.879	− 5.459
42	− 2.859	− .177	−11.842	− 7.909	− 7.737	− 8.047	− 6.966	− 4.660
43	− 6.123	+ 4.317	−10.714	− 4.916	− 7.605	− 7.085	− 6.203	− 5.714
44	− 5.753	+ 5.698	−10.464	− 8.767	− 5.777	−10.951	− 9.719	− 2.179
45	+ .437	+ 1.840	−11.779	−10.118	− 7.574	−10.015	− 7.192	− 4.877
46	−20.600	+24.738	−12.218	−11.044	−12.955	− 5.166	− 9.491	− 1.656
Average	− 5.992	+ 4.596	−10.834	− 6.429	− 8.319	− 8.872	−14.580	+ 3.834

Number of well.	Period X.		Period XI.		Period XII.		Period XIII.	
	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.	A.M. to P.M.	P.M. to A.M.
26	− 8.847	− 1.985	−11.544	− 8.371	+ .027	− 2.643	− 7.042	−11.893
27	− 6.254	− 4.300	− 5.666	− 1.326	− 1.327	− .078	− 8.622	−10.402
28	− 5.967	− 3.026	− 9.403	− 7.794	+ .073	− 2.771	−12.422	− 8.161
5	−11.492	− .936	−13.676	− 6.121	....	....	....	....
40	− 4.385	− 6.769	− 5.200	− 9.709	− 3.273	− 1.964	− 5.867	− 9.357
41	− 6.748	− 5.278	− 8.763	− 7.918	− 1.427	− 2.805	−10.133	− 7.866
42	−12.575	+ .088	−28.963	+12.212	− .864	− 1.800	−10.655	− 7.286
43	− 6.422	− 4.954	−24.451	+10.271	− 3.527	− .550	....	....
44	−11.071	− .495	−16.763	− 1.496	− 3.318	− 2.393	−11.600	− 8.303
45	−35.485	+23.615	−50.897	+29.202	− 1.036	− 8.790	−10.167	− 3.509
46	−11.087	− 3.128	−31.844	+ 9.795	+ 1.336	− .571	−13.222	− 6.661
47	....	....	....	....	+ 1.973	− 1.628	−11.244	−11.232
Average	−10.939	− .652	−18.831	+ 1.704	− 1.033	− 1.644	− 9.179	− 8.467

This table shows that in the majority of cases the rate of fall in the ground-water level is more rapid during the hours from 6 a. m. to 6 p. m. than it is from 6 p. m. to 6 a. m. Now, while there are numerous exceptions to this statement, yet the exceptions are largely confined either to certain wells or else to particular periods, as the following condensed tabulation will show:

		Agreements.	Exceptions.
In well 26 during	13 periods there were	10	3
In well 27 during	13 periods there were	8	5
In well 28 during	13 periods there were	3	10
In well 5 during	10 periods there were	10	0
In well 13 during	4 periods there were	2	2
In well 14 during	1 period there was	1	0
In well 15 during	4 periods there were	3	1
In well 16 during	4 periods there were	4	0
In well 17 during	1 period there was	1	0
In well 6 during	4 periods there were	4	0
In well 7 during	1 period there was	1	0
In well 39 during	4 periods there were	2	2
In well 40 during	8 periods there were	2	6
In well 41 during	8 periods there were	6	2
In well 42 during	8 periods there were	6	2
In well 43 during	7 periods there were	7	0
In well 44 during	8 periods there were	7	1
In well 45 during	8 periods there were	7	1
In well 46 during	8 periods there were	7	1
In well 47 during	2 periods there was	1	1
Making in	129	92	37

There are thus shown to be 71 per cent. of the cases where the mean fall during the daytime is greater than it is during the night. Then, again, of the 37 exceptions, 21 are found in 3 wells and 10 are found in one. If we make the tabulation by periods the case will stand as below:

1888.	Agreements.	Exceptions.
September 18 to 29, Period I, of 11 wells there were	10	1
October 1 to 14, Period II, of 9 wells there were	6	3
October 15 to 28, Period III, of 9 wells there were	4	5
October 29 to November 10, Period IV, of 9 wells there were	6	3
1889.		
May 19 to June 1, Period V, of 4 wells there were	3	1
June 4 to 18, Period VI, of 11 wells there were	9	2
June 20 to 27, Period VII, of 11 wells there were	9	2
July 3 to 17, Period VIII, of 11 wells there were	4	7
July 18 to August 1, Period IX, of 11 wells there were	9	2
August 2 to 16, Period X, of 11 wells there were	10	1
August 17 to 31, Period XI, of 11 wells there were	10	1
1891.		
January 19 to 31, Period XII, of 11 wells there were	5	6
February 14 to 22, Period XIII, of 10 wells there were	7	3

Making in all 129 cases, with 92 agreements and 37 exceptions.

Here, again, 18 of the exceptions occur in periods III, VIII, and XII.

Determining the average change of all of the wells during all of the periods, it is found to be —8.583 inches in 1,000 day hours, and —1.309 per 1,000 night hours. Making a similar determination for periods VI to XIII, inclusive, when the largest number of wells were being measured at the same time, we get —9.972 inches as the change during the day, and —1.917 as the change during the night for each 1,000 hours.

AUTOMATIC RECORDS OF THE FLUCTUATIONS IN THE LEVEL OF GROUND-WATER.

It became evident very soon, in the study of the changes which take place in the level of ground-water, that not only continuous but synchronous records would be required before the real character and extent of these movements could be made known, and early in the summer of 1891 the practicability of obtaining continuous records was established by mounting a pen upon an axis so that a float, resting upon the surface of the water in a well, would cause the pen to record the movements of the water upon a sheet carried by the drum of a thermograph, and Fig. 15 is a reproduction of one of the earliest records thus obtained, the instrument being placed in well 48, which has a depth of 40 feet and is tubed with 6-inch iron pipe down to rock, 37 feet below the surface. There was in this well at the time the first records were obtained 20 feet of water, and it had just been sunk. Water was first reached at a depth of about 25 feet, but after the drill entered the sandstone 2.5 feet the supply of water to the well considerably increased and the head raised 5 feet.

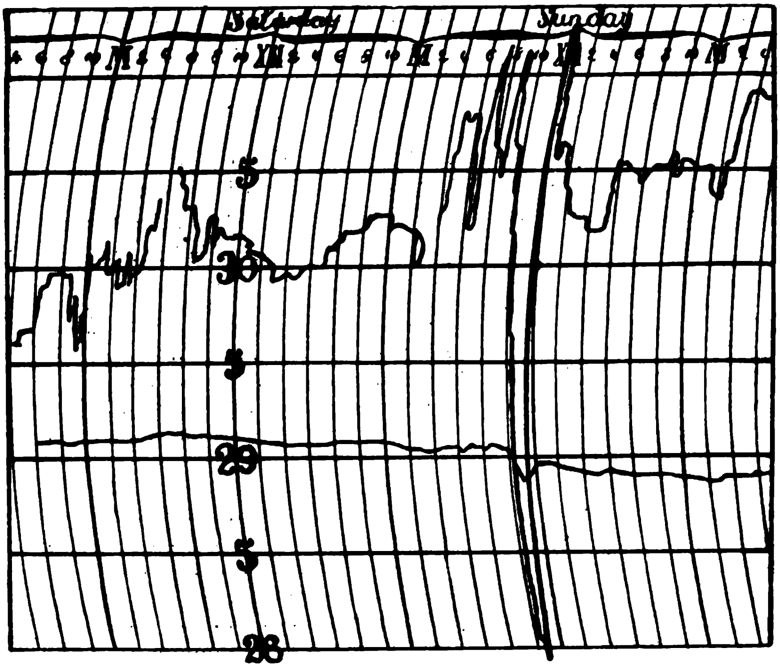

Fig. 15. Automatic record of fluctuations of water in well 48, from 6 p. m., May 30, to 6 a. m., June 1, 1891, with the synchronous barograph record below.

The financial assistance rendered in this investigation by the Weather Bureau, through the U. S. Department of Agriculture, made it possible to have twelve special recording instruments constructed for the purpose of this study, one of which is shown in Fig. 16. The instrument consists of a drum, carrying a record sheet, which is driven by a double marine eight-day clock movement in ten of the instruments, and a one-day movement in the other two. A copper float connected with a lever working upon conical bearings transmits the movements of the water surface to the pen. The arm of the lever to which the float is attached is one-third the length of that carrying the pen, thus producing a curve having an amplitude three times the normal. The fluctuations in most wells, however, have been found so large as not really to require this amplification for any but the smaller short-period fluctuations. The float consists of a hermetically sealed copper cylinder 6 inches long and 3 inches in diameter, loaded so as to float about one-half immersed in the water. The eight guard wires, shown in the figure, attached to the float are for the purpose of preventing surface tension from drawing it against the wall of the well and thus interfering with its free movement.

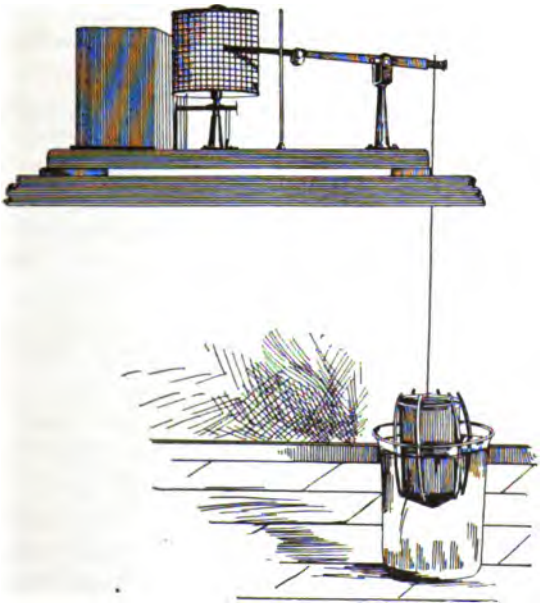

Fig. 16. Self-recording apparatus for registering fluctuations of water-level in wells.

While these instruments have answered very well for the hasty preliminary study for which they were designed, there are several im-

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Note.—It is due to the manufacturer of these instruments, Mr. Henry J. Green, to say here that, considering the few weeks he had at his disposal for the construction of them, and the lack of specific details to guide him, the order was exceptionally well filled.

portant improvements required in them before they are capable of yielding exact records. As some of the imperfections referred to affect the results to be reported here, they will be pointed out in this place. In the first place, through an oversight, due to great haste in the construction of the pieces, no provision was made for easily adjusting the pen to the exact minute on the record sheet when a new one was put in place, and this has rendered it difficult to exactly combine the records so as to show the true time relations existing between the fluctuations of the different wells. In the second place, the screw movement by which the clock is coupled with the drum introduces a periodic error which throws the recorded events slightly out of their true time, but is so small as to seriously affect only the short-period fluctuations, and time has not permitted the application of any correction for it. This method of connection also introduces a third source of error by the considerable slack movement which it necessitates, and to overcome which no provision was made. In setting the clock the drum could be placed, of course, so as to take up all slack, but the errors introduced from this source come through any jar which the instrument might sustain, and in some cases might exceed one hour in time. These facts should be constantly borne in mind when considering the continuous records presented in this report.

THE COMPLEX CHARACTER OF FLUCTUATIONS TO WHICH THE SURFACE OF GROUND-WATER IS SUBJECT.

It is proposed to enumerate here, as preliminary to the presentation of the results which have been secured through the self-recording instruments and associated studies, some of the conditions which affect the level of ground-water, or may be expected to do so.

Possible secular changes in the level of ground-water.

It is a common remark made by many of the older settlers of this state and of Illinois, that the water stands permanently lower in the wells than it did in earlier times, and that many tracts of land which it was then impossible to get upon with a team are now hard enough to do so without difficulty. Without attempting to assign a cause for these supposed or real changes in the level of the ground-water, attention may be called to some changes now in progress tending to produce such alterations as that referred to.

In those sections of country undergoing secular changes of level due to movements of the earth's superficial strata, it is evident that all artesian basins experiencing any differential movement that would alter the relative height of the supply and drainage portions must tend to have established new drainage rates for them, and if the drainage portion of such a basin is being progressively lowered, relatively, by any cause, while the mean percolation of rain into it remains the same, the level of the ground-water would tend to progressively decline.

Then again the depression, by surface erosion, of river beds or the outlet of lakes into which the ground-water of the surrounding highlands drains, must have a tendency to increase the drainage gradient and hence to lower the level of ground-water until equilibrium is established between the drainage and the mean annual percolation.

The water which percolates into the ground and again emerges from it carries away, both in solution and in mechanical suspension, large quantities of the rock constituents with which it has come in contact; and this, unless counteracted by other changes, must tend to develop an increasing porosity or widening of the passageways through which the water moves, and so to decrease the resistance to drainage and hence to lower the general level of ground-water in the region so affected.

If in any considerable tract of country the mean surface consumption of water is increased by a material increase in the annual production of dry matter per acre in the form of vegetation, there must necessarily be a decrease in the total drainage from that section, and for this reason a tendency to develop a lower stage of water in the ground, and through this a drying and hardening of marsh lands such as has been referred to. When it is stated that experiments conducted in England and Germany, and also at this station, all agree in showing that as much as 325 pounds of water are required to be withdrawn from the soil by the roots of plants in the production of each pound of dry matter, it is evident that to double the mean annual production of dry matter in a country must have an appreciable effect upon either the superficial or underground drainage from that region, and if upon the underground drainage, to lower the height of ground-water there and through this to lower the level of lakes, and to harden the marshy lands.

Short-period changes in the level of ground-water.

As has already been pointed out, seasonal and annual changes in the amount of water which falls upon the surface of the ground and percolates into it, have a tendency to develop stages of high and low ground-water in regions so affected.

Since changes in temperature very materially influence the viscosity of liquids, and since variations in the viscosity affect the flow of water through narrow passages like capillary tubes, it may be expected, as will be shown in another place, that both seasonal changes in soil temperature and mean annual ones also exert an influence in developing fluctuations in the level of ground-water through a modification of the rate of percolation and the rate of underground drainage.

Oscillations in the level of ground-water.

Besides the changes in the level of ground-water already pointed out, its general surface is further subject to extremely numerous oscillations of small extent, some of which are almost microscopic in amplitude; indeed, the times of even approximate quiet appear to be extremely rare. The equilibrium of the water in the capillary soil spaces above the surface of the ground-water is so unstable that apparently the slightest cause is sufficient to upset it, causing the water to flow out into the non-capillary spaces, but only to be returned again, often on a moment's notice. There appears to be a zone of soil particles of undetermined depth into and out of which there is a constant ebb and flow of water. The observations to be presented show that oscillations of atmospheric pressure of almost every character affect this underground water-surface. The longer period barometric changes associated with cyclones depress or raise the water-surface, as the case may be; the shorter period changes, which accompany thunderstorms, are registered there, and there are movements which are coincident in time with the semi-diurnal barometric changes. The diurnal changes in soil-temperature, under favorable conditions, produce corresponding rises and falls of the water-surface; and the passage of a train, even where the water is 20 feet below the surface, causes the non-capillary spaces to fill up and empty themselves again as the moving weight approaches and recedes. This ground-water ocean-surface, therefore, like that of the open sea, knows never one moment of rest. The geologic and agricultural significance of these movements must be very great, for here is a water washed zone of rock and soil, having the combined area of all land above ocean level, unless we must except those of the polar zones, which is alternately flooded with water and then exposed to air; and this zone rising and falling through greater and lesser distances, according to the secular and short period changes in the level of the ground-water, must greatly exaggerate the solvent power of soil water over what it would be did these oscillations not exist.

INFLUENCE OF BAROMETRIC CHANGES ON THE RATE OF FLOW FROM SPRINGS, ARTESIAN WELLS, AND TILE DRAINS.

Three of the self-recording instruments referred to were placed, one upon a spring at Whitewater, Wis., one upon an artesian well 300 feet deep situated one-half a mile distant from the spring, and the third so as to register any change which might occur in the rate of flow of water from a tile drain on the Experiment Station Farm.

The method of enabling the instrument to record changes in the rate of flow of water is illustrated in Fig. 17, which shows how it was placed in the spring at Whitewater. The spring in question was encased in a wooden cylinder 3 feet in diameter and the water brought by it discharged through a 1¼-inch gas pipe, 4 feet long, into a vat used for setting milk cans in. The top of the spring curb was covered and the instrument placed as represented in the figure. In the case of the artesian well the principle was the same, for the well discharged from the side of the 6-inch tube through a ¾-inch gas pipe a few inches long, and the float rested directly upon the surface of the water, which stood at all times above the level of the discharge. In the case of the tile drain, the water flowed into a receptacle which had an orifice near the bottom, whose capacity could be altered so as not to allow the receptacle to become full and overflow the top. In all of these cases any change in the rate of flow of water from the ground would produce a change in the head of water discharging through the respective pipes, thus causing the float to rise or fall as the rate of flow increased or decreased.

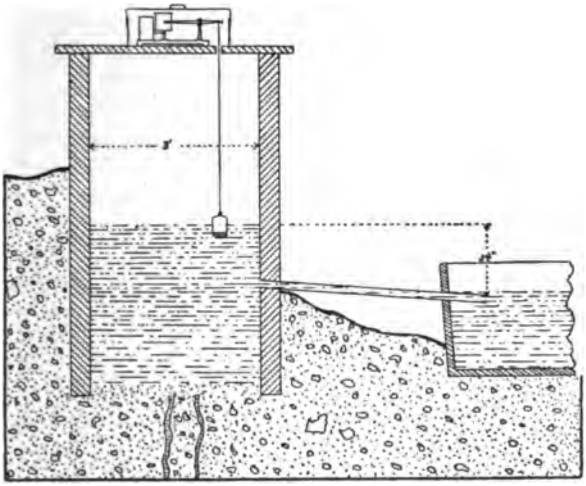

FIG. 17. Method of recording changes in the rate of flow of water from drains and springs.

A facsimile of the synchronous curves obtained from the spring and from the well during two and one-half days is shown in Fig. 18, from which it will be seen that while they are not alike in the minuter oscillations, there is yet a remarkable agreement between them.

There was no barometer record kept at the place where the well and spring are, but the barograph records at the Experiment Station are available for comparison with these curves, but it must be borne in mind that the barograph is situated 45 miles to the westward of the locality under consideration. In Fig. 19 the records of the barograph and that of the spring for May 4 to 16 are placed in juxtaposition, the minor oscillations of the spring being omitted. It requires only a glance at these two curves to see that they are remarkably concordant, considering that they are separated by an interval of 45 miles and that the curves are in themselves so complex. It is true that the changes recorded by the barograph fall a little earlier than the corresponding ones produced by the spring, but as the barometric changes are progressive from west to east a certain interval should be anticipated, even were there no lagging due to other causes.

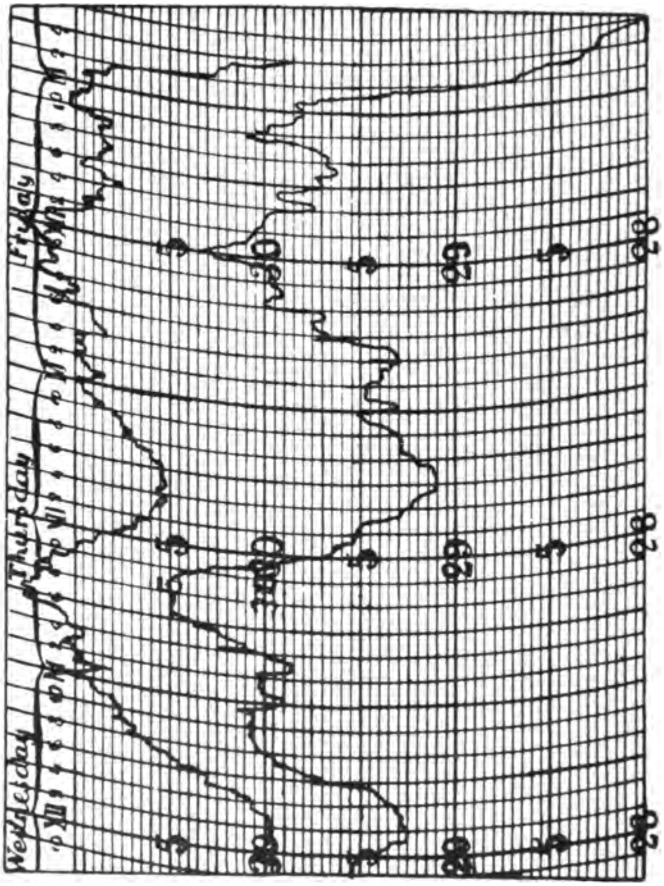

FIG. 18. Synchronous records, showing variations in the rate of flow of water from a spring and from an artesian well at Whitewater, Wis.

So, too, when we compare the barometric curve with that obtained from the tile drain referred to, as shown in Fig. 20, it will be seen that there is here also a close agreement between most of the marked curves which the barograph shows and those produced from the fluctuations in the rate of discharge from the tile drain. The rapid increase in the rate of discharge on Sunday is due to percolation resulting from the rain of 1.10 inch falling during Saturday night and Sunday.

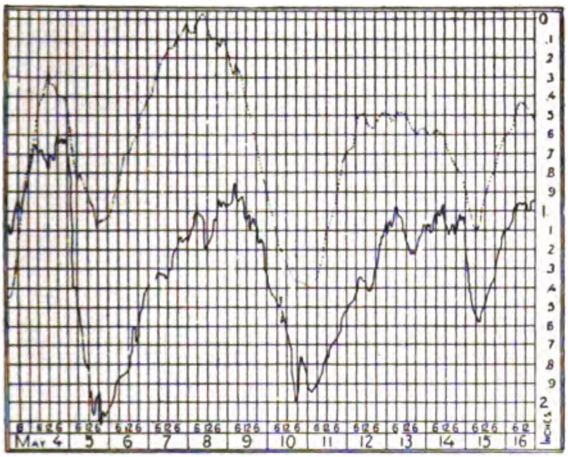

FIG. 19. Fluctuations in the head of a spring at Whitewater, Wis., from May 4 to May 16, and the barograph record at Madison for the same period. Both reduced to natural scale.

The smaller short period fluctuations shown on the drain curve are a portion of them barometric, but not seen to be so because the amplitude of the barometer curve is too small to show their equivalents upon it; the very sharp shortest period curves are many of them due to the pumping action of the wind, which tended to suck air either out of or into the drain and thus modify the rate of discharge.

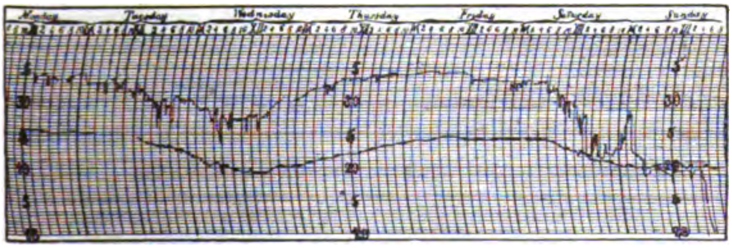

FIG. 20. Synchronous changes in the rate of discharge of water from a drain, and the barometric changes during one week.

In the case of the spring under consideration, the barometric changes which occurred during the intervals when the records were kept caused the head to range from less than 12 inches to more than 14 inches, and this would give a theoretical variation in the rate of discharge amounting to 8 per cent., the water flowing this much faster during one interval of low barometer when compared with that taking place during an immediately preceding high barometer. In the case of the tile drain, with the water discharging from the gauge under a head of .585 inch, a sudden rise in the barometer amounting to .1 inch decreased the head in the gauge almost as suddenly .15 inch, and considering the velocity of discharge to vary as the square root of the head, the water was discharging under the high pressure 15 per cent. less rapidly than previous to the change of atmospheric pressure.

The water supply at the waterworks for the city of Whitewater is derived from an artesian well 979 feet deep, the water flowing into a reservoir 106 feet in diameter in which there is an overflow pipe having an inside diameter at the top of 9.75 inches. The pumps are coupled directly to the well in such a manner as to draw upon the reservoir when the rate of flow from the well does not equal that of pumping. Through the kindness of the proprietors, Messrs. C. G. Gray & Co., I was permitted to place one of my instruments in the reservoir so as to determine whether or not this well was subject to variations in the rate of flow analogous to those observed in the spring and shallower well near by already referred to. To obtain the rate of flow of water from the well the float of the recording instrument was placed upon the water in a cylinder which was partly submerged in the reservoir, the bottom of the cylinder being perforated with several small holes so as to establish communication with the water in the reservoir without allowing the float to be disturbed by wave action.

During the pumping, which occurred once daily, the water was lowered in the reservoir from 2 to 4 inches, and the instrument was so adjusted as to record the length of time required for the reservoir to regain its original level after pumping, and to show any change of head which might occur while the reservoir was overflowing.

One of the eight-day instruments was first placed in the reservoir, and Fig. 21 shows a portion of the record obtained with it, where it will

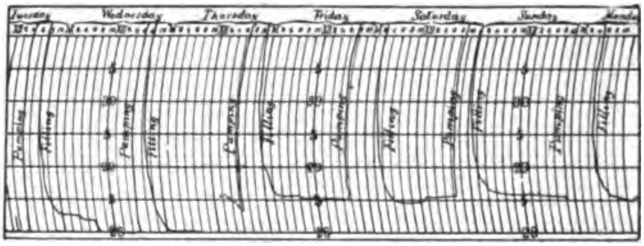

FIG. 21. Changes in the rate of flow from the artesian well at the city waterworks, Whitewater, Wis.

be seen that not only did the time required for the reservoir to regain its original level vary but also that this level did not remain constant when once attained. It should be observed that the curve showing the rate of filling covers only the last portion for each day.

In order to be able to measure the time of filling more exactly one of the one-day instruments was substituted for the one first used, and a record obtained during 10 consecutive days, with results as given below:

Table showing variations in the rate of flow of water from the artesian well at the city waterworks, Whitewater, Wis., from May 31 *to June* 9, 1892.

Cu. ft. per min.
May 31, well discharged 1103.09 cubic feet in 77.82 minutes, = 14.175
June 1, well discharged 1103.09 cubic feet in 71.44 minutes, = 15.441
June 2, well discharged 1103.09 cubic feet in 75.27 minutes, = 14.655
June 3, well discharged 1103.09 cubic feet in 72.71 minutes, = 15.171
June 4, well discharged 1103.09 cubic feet in 76.54 minutes, = 14.412
June 5, well discharged 1103.09 cubic feet in 79.09 minutes, = 13.947
June 6, well discharged 1103.09 cubic feet in 72.71 minutes, = 15.171
June 7, well discharged 1103.09 cubic feet in 76.54 minutes, = 14.412
June 8, well discharged 1103.09 cubic feet in 73.99 minutes, = 14.909
June 9, well discharged 1103.09 cubic feet in 72.71 minutes, = 15.171

On June 1, 7, and 8, at the time of sudden showers, the water-level in the reservoir changed so as to carry the float up through .1, .5, and .4 inch respectively, and this when the water had been overflowing at its normal height during several hours. The shower when the water rose more than .5 inch was a very heavy one, but all of them were of short duration. As the overflow was within three feet of the place occupied by the instrument it does not appear probable that any wind action, by forcing the water to that side, could have produced the change of level observed, and that this could have been the cause is rendered still more improbable by the fact that the water rose and fell so as to give a steady curve, as shown in Fig. 22. Neither does it appear possible that any shower could have increased the head to the extent observed, by direct precipitation into the reservoir, for the overflow pipe was never carrying water at nearly one-half of its full capacity. If no such explanation as has been suggested is admissible, the conclusion must be that these deep wells are subject

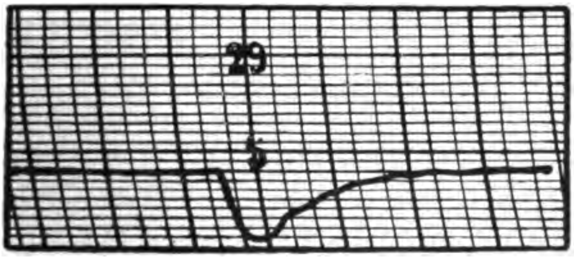

FIG. 22. Sudden changes in the flow of water from the artesian well at the city waterworks, Whitewater, Wis. Natural scale.

to sudden increases in flow such as have been shown to be true of the spring, the drain, and the shallow artesian well referred to.

It should be observed here also that the changes in the rate of flow recorded by the eight-day instrument are coincident in time, and also in character, with the changes which took place in the spring and other well in the same vicinity, and it would appear, therefore, that barometric changes exert a far reaching influence upon the underground drainage coming from any and all depths below the surface. The magnitude of this influence is so great also that the aggregate increase or decrease in the flow of water from large subterranean drainage areas, as low and high pressure waves travel over them, must be absolutely very great and, it would seem, capable of registration by suitable instruments on very many, if not upon all, rivers, and possibly all lakes as well.

BAROMETRIC OSCILLATIONS IN THE LEVEL OF WATER IN WELLS.

The evidence is overwhelming that barometric changes exert a very marked and nearly if not quite immediate influence upon the level of water in a well. That sudden and large changes in the barometer are closely associated with marked changes in the level of water in wells is strongly suggested by the facsimile curves shown in Fig. 15, already referred to on page 40, but here the amplitude of the barometer is too small to make a satisfactory comparison between them in any except the general features.

In order that a closer comparison might be made in this particular, the two one-day instruments were placed one upon well 48 and the other upon the air barometer represented in Fig. 23, which was constructed for this purpose and to ascertain whether or not some of the short period fluctuations shown both by the wells and by the spring and drain might not be due to a pumping action of the wind.

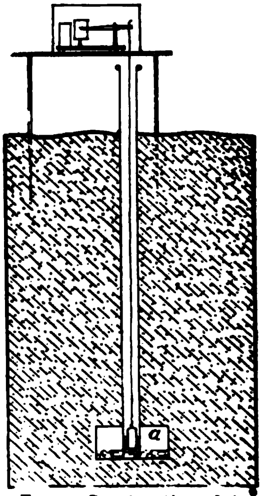

Fig. 23. Construction of air barometer.

This instrument, apart from the recording portion which has been described, consists of a galvanized iron cylinder, 4 inches in diameter and 8 feet long, to the lower end of which is attached a cylinder of the same material 18 inches in diameter and 8 inches deep; this larger cylinder confines a quantity of air which, by its changes in volume, alters the level of the water shown and thus causes the float to rise and fall with each change of atmospheric pressure. The air receptacle is placed six feet below the surface of the ground and the earth filled in over it so as to avoid marked temperature fluctuations. The instrument thus constructed proved to be quite satisfactory for the purpose designed, and has an amplitude five to six times that of the mercurial barometer.

How closely in accord the fluctuations recorded by this instrument and by the one placed upon the well are will be seen from Fig. 24, which shows the curves produced during the 10 hours closing 7.50 a. m. May 30, 1892. It will be seen that there are on the well curve two short interval changes, one upward near the left end and the other

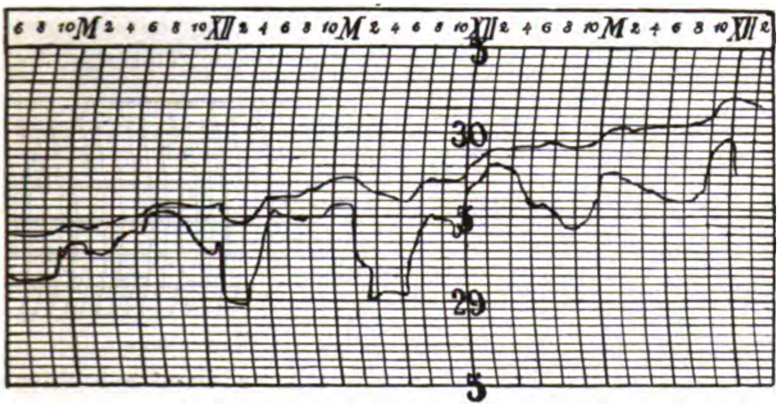

FIG. 24. Synchronism of barometer and well changes as recorded by one-day instruments.

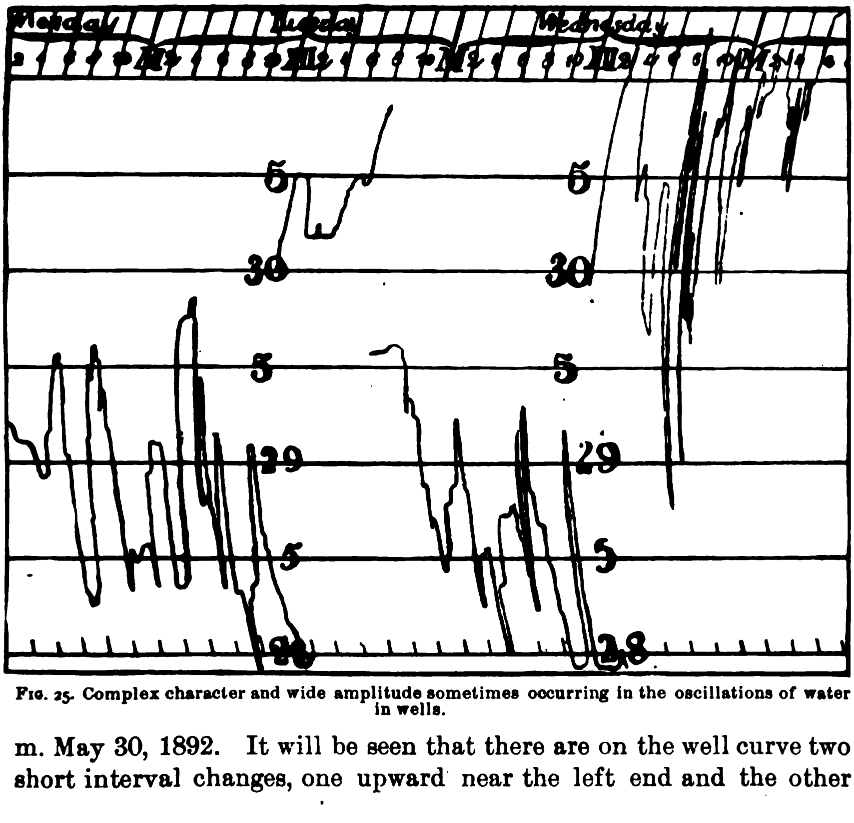

FIG. 25. Complex character and wide amplitude sometimes occurring in the oscillations of water in wells.

downward to the right of the center, which have no analogous ones in that of the air-barometer, otherwise there is an extraordinary agreement in all features except amplitude.

At times these barometric fluctuations are both of extreme amplitude and of great frequency also; this is clearly shown in Fig. 25, where the amplitude was so large as to require the pen to be set over four times between 2 p. m. Monday and 6 a. m. Thursday, and at intervals during this period the changes were so rapid as to force the lines close together. The general frequency of these changes are better shown in Fig. 26, which is a tracing of the curve produced during 24 hours ending April 30, 1892, by well 48.

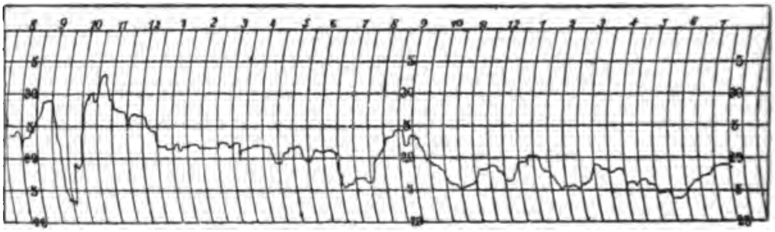

FIG. 26. General character of fluctuations of water in well 48 during 24 hours.

The synchronism of movement which the ground water in different wells in the same locality exhibits is shown in Plates II to V, where the curves are reproduced so as to show the actual changes of level as they occurred from day to day.

It should be borne in mind in studying these plates that the direction of the movement of the water surface in the well was opposite to that shown by the curve, a descent of the curve across the page meaning a rise of water in the well and *vice versa*, and this is true for all of the curves obtained with the instruments used. Since a rise of the barometer is associated with a tendency of the water to fall in the well and a fall of the barometer with a tendency to rise, the method of mounting the pen causes that of the barograph and that of these recording instruments to move in the same direction at the same time.

It will be seen from a study of these plates that nearly all of the marked sudden barometric changes are shown, in a greater or less degree, on nearly all of the wells. The long period barometric oscillations are usually recorded by the wells, but these are much more obscured by the percolation of rain into the ground and by the general lowering of the ground-water surface by subterranean drainage. That this should be so is plain, because it very often happens that, at a given well, the downward descent of the water-level, due to drainage, is exactly compensated for by the rise due to a fall in the barometer, and in such a case the tracing for that period will be horizontal, while in that of another well in which the water chances to be rising at the same time in consequence of percolation, the barometric effect will be added to that of percolation, so that while the first well shows no curve corresponding to that of the barometer the one for the second shows it in an exaggerated form. The evidence of the influence of long period barometric oscillations must therefore be sought, generally, in a variation in the mean rate of change in the fall or rise of the ground-water surface.

It appears to be a general rule that the long period barometric oscillations, and perhaps all barometric changes as well, exert a greater influence upon the water of the deeper than upon the shallower wells, and this, too, should be expected from what has been said, because the deeper wells are less affected by local percolation into them and the reverse action which is a consequence of it.

SEMI-DIURNAL OSCILLATIONS IN THE LEVEL OF WATER IN WELLS.

It has already been pointed out that the water of wells exhibits a tendency toward diurnal oscillations, the water, as a rule, standing higher in the morning or else not having fallen as rapidly during the night. The continuous records obtained from the wells, from the spring, and from the drains show very clearly, at times, that the level of water in the non-capillary spaces in soil is subject to regular semi-diurnal oscillations, as a careful inspection of the various plates will prove.

To render these semi-diurnal changes more apparent, I have selected a week when there were no large barometric changes and have taken a well in which the water surface was nearly stationary so far as drainage and percolation are concerned. The week selected was that ending July 11, 1892, and the well was No. 33. Side by side with this the curve produced by the air-barometer has been placed, and with it also that of the Richard barograph of the same date. The curve of the Richard barograph is magnified about six times and was constructed as follows: The record sheet was passed through the field of a compound microscope, provided with an eye-piece micrometer, and magnifying 43 diameters. The changes in the position of the barometric curve on the record sheet were measured at the crossing of each of the two-hour lines by bringing one end of the micrometer scale always to the lower side of a distance line and reading the distance to the under side of the barometer curve in divisions of the micrometer scale, and as fifty divisions of the micrometer just spanned the distance lines it was possible to read the changes very closely and to plot them on a large scale very accurately. The two barometric curves and that of the well are shown on the upper portion of Plate VI, where the coincident semi-diurnal changes are very evident on nearly every day of the week. It will be seen that there is a minor minimum falling from 9 to 11 p. m., and a major one falling from 7 to 10 a. m. On the same plate there have been plotted the curves of the same well for the two following weeks, and also that of the air-barometer for the last week, and it will be seen, when these are all compared, that, while the more numerous short period barometric fluctuations tend to obscure the semi-diurnal ones, these are evidently there and in the same relative position with respect to time.

The 300-foot artesian well at Whitewater and the spring also show these same semi-diurnal fluctuations, but the long barometric oscillations were so great during the weeks when the records were kept that the semi-diurnal oscillations are much obscured by them, and there they appear to fall at about the same times of the day also as they do with the shallower wells at Madison.

I find in the Report of the Transactions of the British Association for 1883, p. 405, the following, under the subject—"On the Attractive Influence of the Sun and Moon Causing Tides, and the Variations in Atmospheric Pressure and Rainfall Causing Oscillations in the Underground-Water in Porous Strata." By Isaac Roberts, F. G. S.:

> The investigations have been made at Maghull, which is an agricultural district about 8 miles to the northeast of Liverpool, and relate to movements in the underground water of the Triassic rocks, which lie beneath the surface of the ground. The water in these rocks is by capillarity made to form an inclined plane toward the sea, which, at the point referred to, has its surface 60 feet above mean sea level. The water plane was shown to be in a state exceedingly sensitive to the following influences, namely, atmospheric pressure, lunar attraction, and solar attraction.
>
> In order to determine the relative extent of these and other disturbing influences upon the water plane, an artesian well was sunk in the Triassic rocks to a point below mean sea level and the rise and fall of a column of water 60 feet in height, freed from the friction in the rocks, was used as the means of registering these disturbances in the water plane, by using a mechanical combination of a float and drum, caused to revolve by clockwork, to trace a curve upon the diagram paper.
>
> The curve showed the extent, from moment to moment, of the atmospheric variations, and also the effects of the attraction of the sun and moon upon the water plane in producing oscillations in the first case and true semi-diurnal lunar and solar tides in the latter case. The effects of rainfall were also shown on the diagram.
>
> It was also shown that there were periods when all of the forces which have been named were in equilibrium, the water plane remaining in a state of perfect quiescence during those periods.

The statement to which attention is here called especially, is the one ascribing certain fluctuations in the level of the water in this well to both solar and lunar tidal disturbances. I have not, as yet, been able to learn whether the paper to which the above report refers has been published or not, and do not, therefore, know the character of the evidence upon which these statements are founded. There is certainly no unequivocal evidence presented by any of the curves obtained in the investigation here which would lend support to the view that a lunar tidal effect has been exerted large enough to be recorded by the instruments used. The apparently entire absence of any progressive change in the time of day at which the maxima and minima occur is the strongest evidence which can be presented against the view that a lunar influence is here recorded. There is, of course, nothing in the time relation which would disprove a solar tide; but if a solar tide is admitted to be recorded, there then appears no reason why, at times at least, a larger one should not also be recorded, having the proper time relations for the moon. Some of the wells at Madison, included in this study, are deeper than the one used by Mr. Roberts and extend below the level of Lake Mendota in the Potsdam sandstone. The still deeper wells at Whitewater also find their water in a porous sandstone, so that the only condition apparent, which is fundamentally different in the well of England, is the close proximity of an oceanic body of water which is, itself, subject to tidal fluctuations. This being true, one is led to suspect that in case the wells in question do exhibit both solar and lunar tidal oscillations they, in some manner, may be a reflex of the oceanic tides.

We are told, however, that the well in question is some 8 miles distant from the sea and that the water "*is by capillarity* (the italics are the writer's) made to form an inclined plane toward the sea, which at the point referred to has its surface 60 feet above mean sea level." Now, were it true that the water is sustained in the well by capillarity to a height of 60 feet in the soil, which the writer knows of no sufficient evidence to prove, it is then required that a rise and fall of the ocean level permits capillarity to increase the height of the soil water when the length of the water column is diminished by the rise of the tide on the coast, but this implies that a force which is able to carry the water to a greater height in the soil is unable to retain it there after it has done so, for otherwise the level of the water in the well would not be affected.

If the oceanic tidal wave is transmitted to the well it would seem that it must be the result either of a direct shock or, what is much more likely, through a deformation of the rock strata by the loading and unloading of the coast.

It had occurred to the writer before reading the notice of Mr. Roberts' results, that in case the superficial strata of the earth are subject to any deformation by tidal stress, the unequal strength of the confining beds of an artesian basin, or the change of volume due to warping such beds, if of equal strength, must necessarily be made evident by a change of level in any column of water sustained by the hydrostatic pressure of such a basin.

The calculated magnitude of these disturbances and of the barometric and tidal loading and unloading of continents and their margins given by G. H. Darwin, had led me to anticipate, for the tidal effect, a very pronounced oscillation of the water-level or pressure in the deeper artesian wells having extended basins. If such oscillations do exist in any of the wells upon which the observations here detailed have been made, they are so masked by the semi-diurnal oscillations just described, evidently not due to this cause, as to require a more critical registration and analysis of them than has been possible in this brief study.

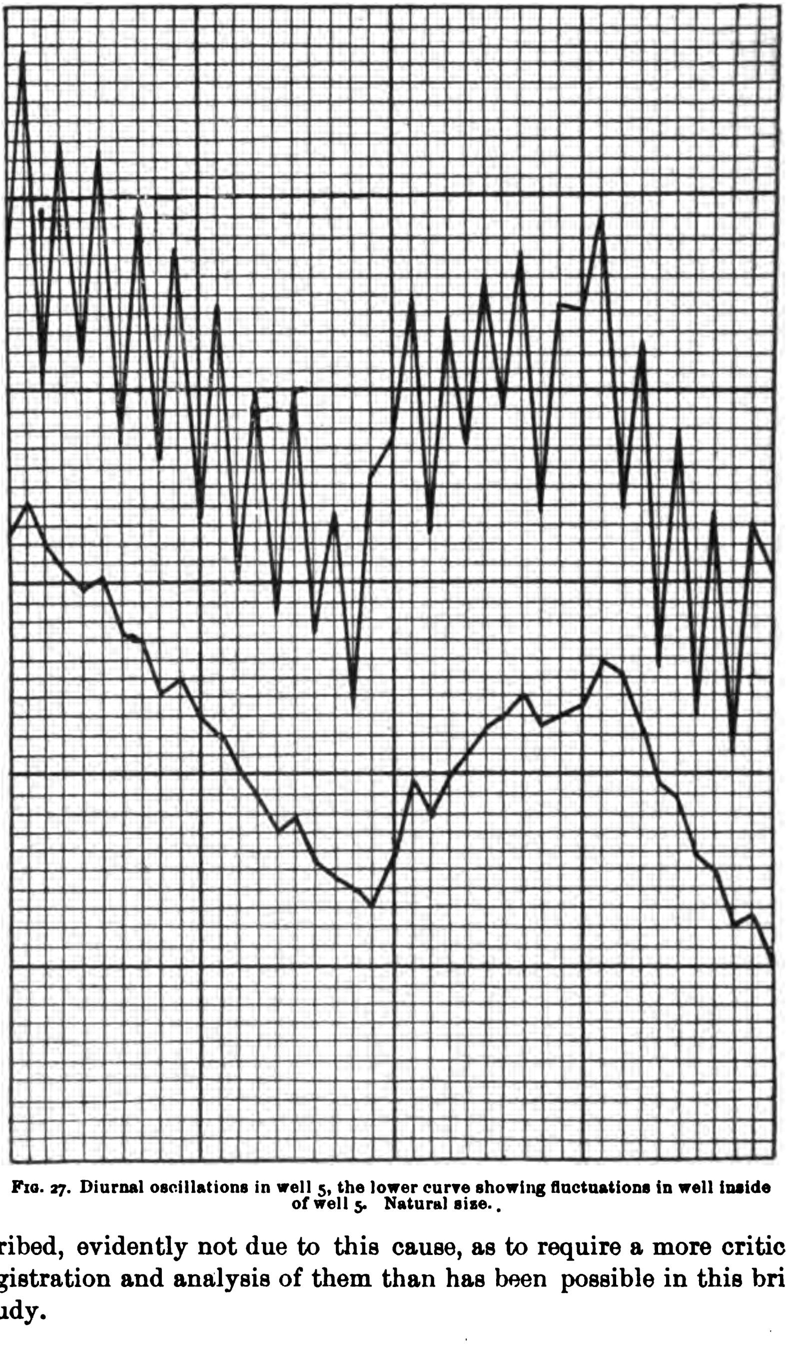

FIG. 27. Diurnal oscillations in well 5, the lower curve showing fluctuations in well inside of well 5. Natural size.

INFLUENCE OF DIURNAL CHANGES IN SOIL TEMPERATURE IN PRODUCING CORRESPONDING OSCILLATIONS IN THE LEVEL OF GROUND-WATER.

The twice-daily observations recorded on Plate I and referred to on page 31 show very clearly that in certain wells and at certain times there is a marked diurnal change of level in the ground-water surface. In Fig. 27 is given a section of Plate I, natural scale, showing the diurnal changes in the level of water in well 5 during the days from July 18 to August 6, 1889. From this it will be seen that the water rose during the night and fell during the day to the extent of a full inch or more. The curve plotted below the one of larger amplitude shows the changes of level which occurred in the center of the same well and during the same time, the two sets of observations being simultaneous. The circumstances are these:

The ground-water level had fallen until well 5, now in question, was likely to become dry. In order not to lose the records it was deepened by boring a hole in the center and curbing it with sections of 5-inch drain tile in the manner represented in Fig. 28, which shows the two water surfaces, whose fluctuations are recorded in the last figure. The original well, having an inside diameter of one foot and a depth of 5.5 feet, was bricked up to within 2 feet of the surface and then finished with a section of sewer pipe, as shown in the cut, where the character and arrangement of the soil through which the well penetrated may also be seen.

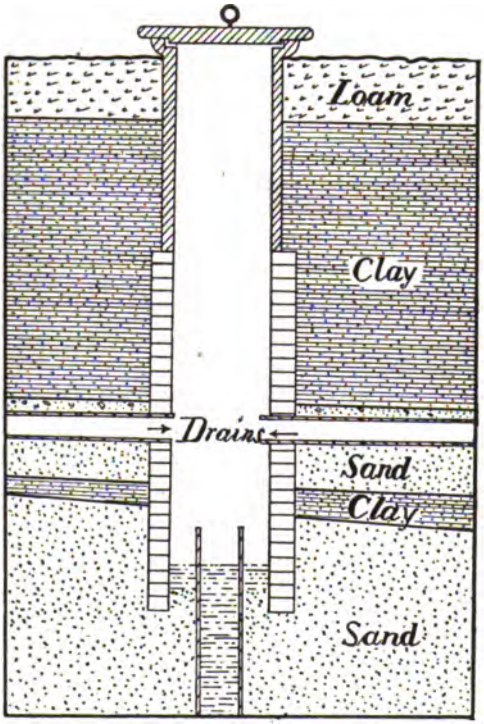

FIG. 28. Construction of well 5, and the character of the soil through which it penetrates.

The facts are, strange as it does appear, that under these conditions and in such close juxtaposition oscillations so unlike in their character as the two under consideration were produced simultaneously. The level of the water in the outer well oscillated so as to stand in the morning from .1 to .3 inch above the level of the water in the inner one and at night from .5 to 1.2 inch below that surface, and these differences were maintained with only the unglazed section of drain tile separating them. During the day, then, presumably, water was flowing from the inner well over into the outer and larger one, while the fact that the water in the outer well rose to a height exceeding that in the inner one shows that some of that water at least must have come into the well from a level above the bottom of the outer well. As shown in Plate I, the large oscillations in this well became very pronounced and constant only a short time before it became dry, and the inner well did not take up the marked changes in level after the water fell below the bottom of the original well. No other well of this series, although constructed in the same manner, showed such marked oscillations as this one. Referring again to Plate I, it will be seen that several other wells did show them, but that there is something apparently very capricious about the starting and stopping of these oscillations. Wells 45, 43, 41, and 40 took on these strong oscillations just after they had been deepened, while well 44 did so without being deepened at all. Wells 40 and 43 oscillated in this marked manner only a few days, while well 41 did so from August 3 until after the middle of September. From the 3d of September until after the 15th all of the wells showed a tendency toward an increased diurnal fluctuation. When these fluctuations were first observed in the fall of 1888, as already referred to—the one in the corn exhibiting the greatest oscillations, while the one in the stubble showed least, as represented in Fig. 1—it was then thought that these differences in the magnitude of the oscillations might be due to differences in the daily amounts of water withdrawn from the soil by vegetation. The observations of the following season showed that this could not be the chief cause of the difference, for then well 5 was on a blue-grass sward with the grass cut short at the time the oscillations were most marked, while well 41, penetrating fallow ground, oscillated much more than did the wells on either side having corn growing about them. Another peculiar feature about these oscillations is the fact that during the years from 1888 up to the

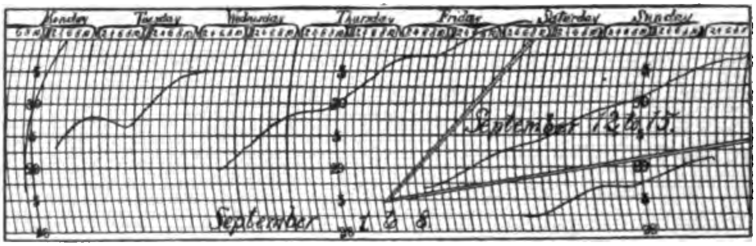

Fig. 29. Dying away of diurnal oscillations in well 5 from September 1 to 14, 1891.

present time no such marked changes in level of the water were revealed by twice-daily observations taken in the morning and evening until past or near the middle of July, from which time there is an advance toward a maximum, occurring some time in August and then a dying away again until along toward the middle of October, when they again became inconspicuous.

In the fall of 1891 the improvised self-recording instrument referred to was placed upon well 5, September 1, just as the oscillations in question were beginning to die away, and Fig. 29 shows these changes from September 1 to 3 and again on September 12 to 14, when their amplitude had become almost inappreciable. In Fig. 30 are also plotted the curves for wells 42 and 44 and the drain from July 25 to 28, 1892, when these oscillations are beginning to become pronounced. It will be seen by referring to Plate V that these diurnal oscillations were beginning to be evident in the previous week.

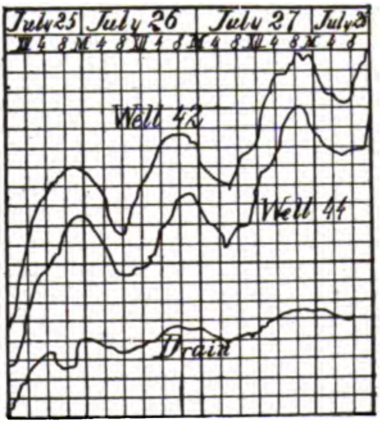

FIG. 30. Diurnal oscillations of water in wells and drain due to diurnal changes in soil temperature.

In the spring of the present year a galvanized iron cylinder 6 feet deep and 30 inches in diameter, provided with a bottom and water tight, was filled with soil, standing its full height above the ground in the open field. In the center of this cylinder and extending to the bottom, a column of 5-inch drain tile was placed and the soil filled in about it and packed as thoroughly as practicable. Water was poured into the cavity formed by the tile until it was full, and allowed to percolate into the soil so as to saturate it and leave the water standing nearly a foot deep in the well. When the water in this artificial well had become nearly stationary one of the self-registering instruments was placed upon it, the object being then to ascertain whether water thus circumscribed in a well would exhibit fluctuations at all analagous to those observed in ordinary wells, and the apparatus as used is shown in the engraving, Fig. 31. In order to avoid any complications due to percolation, the apparatus was provided with a cover which could be put on in times of rain and removed again during fair weather. The first records showed a small diurnal oscillation, and as the season advanced these increased in amplitude until

FIG. 31. Apparatus used in demonstrating the influence of temperature in producing diurnal oscillations of water in wells.

finally the water rose in the well during the day of July 8 1.8 inch and fell during the following night 1.84 inch.

After these diurnal oscillations had become so pronounced and so constant a series of thermometers were introduced into the side of the cylinder, extending to different distances from the surface, and a record kept of the changes in the soil temperature; and the result of these observations was to show that the turning points in the water curve fell exactly upon the turning points of the temperature of the soil in the cylinder. When this fact was ascertained, to show whether the correspondence in the time of the two curves was due to a diurnal cause, other than temperature, which had its turning points so related to those of the temperature as to cause the two to accidentally fall together, cold water was brought from the well and, with a spray pump, applied to the surface of the cylinder all around. The water was applied on a hot, sunny day just after dinner, when the water was rising in the well, and the result was an immediate change in the curve, the water beginning to fall in the well and turn the pen up. The water was then turned off, and the result of this change was to stop the fall of the water in the well, as shown by a change in the direction of the curve downward again. After the lapse of about another hour the water was again turned on, with the result first obtained, and again when the water was withdrawn the curve was once more reversed; a tracing of the curve obtained during these trials is represented in Fig. 32.

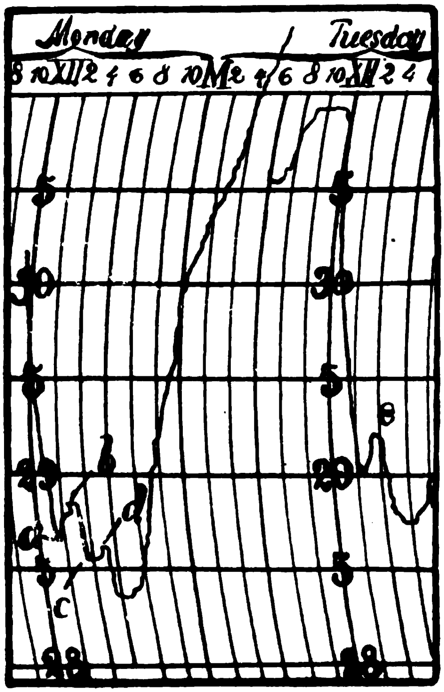

FIG. 32. Changes in the level of water in the well in the cylinder produced by pumping cold water on the sides of the cylinder; *a* and *c* show times of applying the water, *b* and *d* show when the water was withdrawn, and *e* shows curve produced by sudden thunder shower.

These experiments showed that there was a positive connection between changes in the soil temperature and changes in the movement of water in the soil. Since the water left the well and entered the soil with a lowering of the temperature, it follows that the observed changes could not be the result of a change in the volume of the cylinder due to shrinkage and expansion, for the movements of the water were in the opposite direction from what a change in volume would have produced.

The quantitative relation existing between the movement of the water in the soil and the change in temperature is expressed below.

Date.	Mean temperature of soil.		Amount of change in temperature.		Amount of change in water.	
	A. M.	P. M.	A. M. to P. M.	P. M. to A. M.	A. M. to P. M.	P. M. to A. M.
	° C.	° C.	° C.	° C.	*Inches.*	*Inches.*
July 7	19.4	26.3	+ 6.9		+ 2	
July 7–8	26.3	19.4		— 6.9		— 2
July 8	19.4	23.5	+ 4.1		+ 1.8	
July 8–9	23.5	20.7		— 2.8		— 1.84
Mean			5.175° C.		1.91 *in.*	

Here we have a mean change in water-level amounting to .369 inch for each degree C.

Taking the period from June 6 to 9 we have—as below—

Date.	Mean temperature of soil.		Amount of change in temperature.		Amount of change in water.	
	A. M.	P. M.	A. M. to P. M.	P. M. to A. M.	A. M. to P. M.	P. M. to A. M.
	° C.	° C.	° C.	° C.	*Inches.*	*Inches.*
June 6	17.3	22.7	+ 5.4		+ 1.22	
June 6–7	22.7	18.3		— 4.4		— 1.17
June 7	18.3	20.5	+ 2.2		+ .72	
June 7–8	20.5	17.4		— 3.1		— .87
June 8	17.4	20.5	+ 3.1		+ .87	
June 8–9	20.5	17.3		— 3.2		— 1.1
Mean			3.57° C.		.99 *in.*	

In this case we have a mean change in the water-level of .276 inch for each degree C. The cavity into which the water percolated and from which it was again withdrawn with each change of temperature had a diameter of 5 inches, so that the amount of water which left the soil and entered the well was about 6 cubic inches for each degree C. I suppose it was also true that the non-capillary spaces in the soil above the water level in the well were also filled to a certain depth and emptied again, so that the total movement of water in the circle of soil 30 inches in diameter was something more than the 6 cubic inches stated above.

In another cylinder, 10 feet long and 1 foot in diameter, standing in a large silt well 6 feet deep and 4 feet in diameter, the water rose and fell daily between July 15 and 18 an average of 3.33 inches as measured by the change of level of water in a glass tube communicating with the bottom of the cylinder. And, in this case, I suppose the surface of the ground-water in the cylinder rose and fell each day through the mean distance stated. How great the diurnal change of the soil-temperature may have been in the cylinder is not known, but as the cylinder stood below the level of the ground surface in a cavity into which water from the drains was discharging, I suppose that the diurnal range in the cylinder could not have exceeded 2° or 3° C. below the surface of the ground.

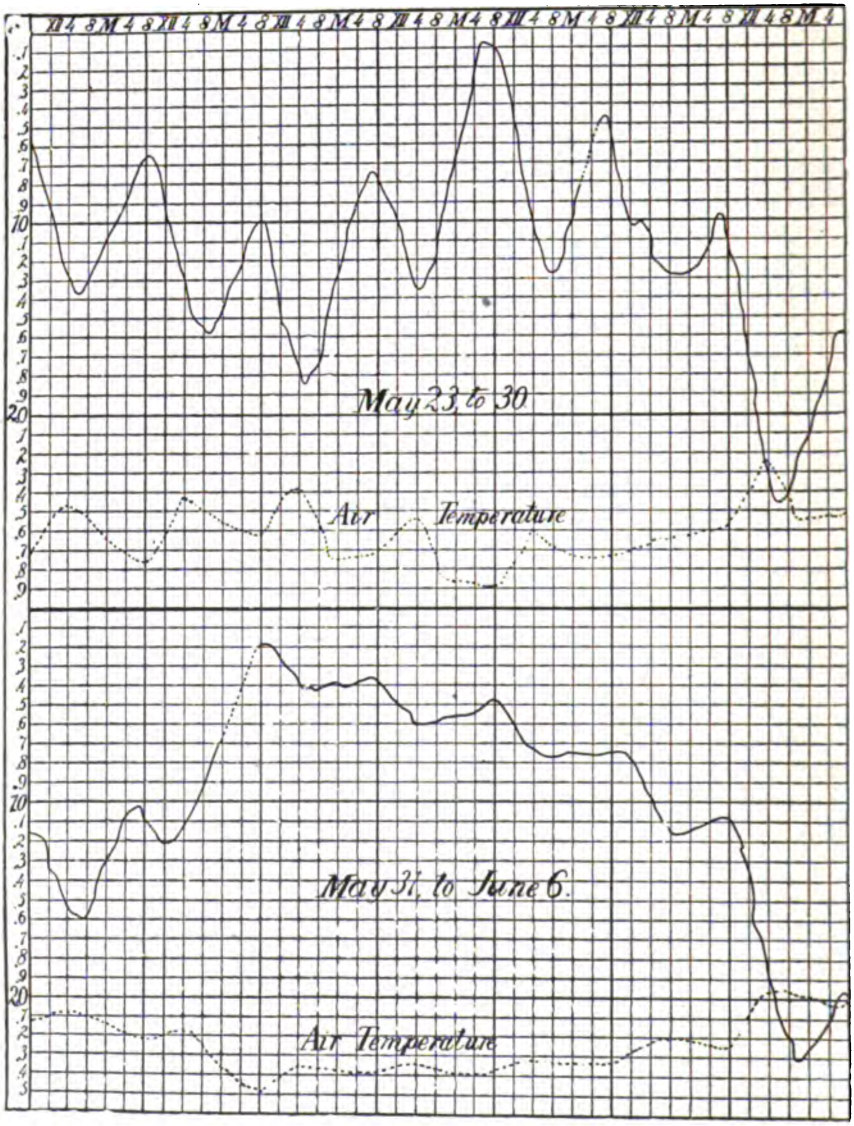

FIG. 33. Diurnal changes in level of water in the well in the cylinder from May 23 to June 6, 1892, and the corresponding air temperatures for the same period.

In Fig. 33 the changes in the level of the water in the well in the cylinder are plotted for two weeks, and side by side with these is plotted the tri-daily air temperature as observed at Washburn Observatory. Here it will be seen that there is apparently no evidence of barometric fluctuations, but a close agreement with the temperature curve.

There is, therefore, in my judgment, no ground for reasonable doubt but that these diurnal oscillations of the water level in the two cylinders were due to an oscillation in the intensity of the capillary power manifested in the soil contained.

To ascertain whether temperature changes in the soil of the field produce a manifest movement of the soil water, it is required to show, in the first place, diurnal oscillations which are evidently not barometric, and second, that the turning points of these curves are on the turning points of the soil temperature in the zone in which the movement of the water takes place. That there are diurnal oscillations evidently not related to any of the observed barometric changes of pressure, has been pointed out, and it remains to show that these do or do not fall into unison with the diurnal temperature curve.

My first effort in this direction was to ascertain whether any probable change of temperature in the wall of the wells was capable of producing the amount of movement observed, and to do this an apparatus was constructed and set in the soil, consisting of a double walled cylinder taking the place of the tile in the well, and a current of warm water, having a temperature of from 70° to 90° F., was kept circulating through it during three consecutive hours on three different days. One of the one-day recording instruments was used to register the fluctuations in the level of the water in the well. There was in no one of these trials any change in the curve which appeared to have any connection with the time of beginning or closing of the experiments, and yet the changes in the temperature of the walls of the well must have been greater than the diurnal range due to atmospheric changes of temperature. I then buried bodily a thermograph, first at a depth of 5 feet and then at a depth of 18 inches. The degree lines in this instrument were too close to detect more than the slightest diurnal change at the greater depth, but at 18 inches the diurnal range was appreciable but could not be measured very accurately, and as the instrument in its box occupied a space of 9 inches, the temperature change recorded could not be located at any definite plane. I then constructed a thermometer, in the form repre-

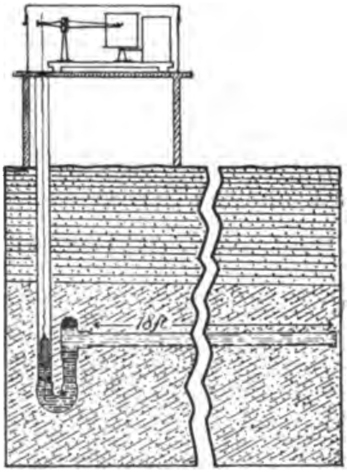

FIG. 34. Construction of new form of self-recording soil thermometer.

sented in Fig. 34, out of 1¼ inch gas-pipe 18 feet long, and filled it with alcohol, which was made to act upon a plug of mercury in the bend of the tube, the latter moving a float which was attached to one of the recording instruments used on the wells. Only an approximate calibration of this instrument was attempted, and this was done by placing a soil thermometer in contact with the center of the tube in the soil and keeping a record of its changes as checks upon the other.

The curve produced by this instrument, placed 18 inches below the surface, and that of a thermograph sheltered at a height of one foot above the ground at the place, giving the air temperatures for the same period, are shown in Fig. 35. Here it will be seen that the soil at 18 inches below the surface is subject to a diurnal oscillation amounting to about 1° F., and that the lowest temperature in the soil occurs, at this level, a little after noon and the highest a little after midnight.

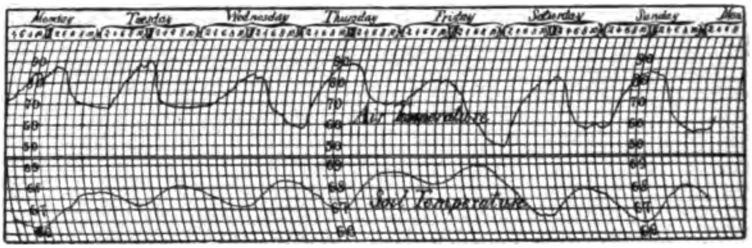

FIG. 35. Diurnal changes in soil temperature 18 inches below the surface, and corresponding air temperature for the same period.

We have no observations, as yet, which definitely settle from what level the water, which produces the rise in the well, comes, but I know no reason for supposing that the chief part comes from above the 18-inch level. If the water comes from below the 18-inch level the temperature changes which effect its movement should be expected to lag still more behind those of the air and so bring the highest temperature, not a little after midnight, but at some later interval. Referring to the figures showing the diurnal oscillations in question, it will be seen that the lowest points in the curves, which represent the highest water in the well, and which correspond to the warm epochs in the soil-cylinder referred to, occur at from 6 to 8 in the morning and, as the level of the water in the wells and that which discharges into the drain is more that twice the depth of the soil thermometer below the surface, there appears no great improbability that the lagging of the temperature wave is entirely sufficient to cause the percolation into the wells to occur at the time at which the curves show that it does take place.

The reason for the absence of oscillations during the spring and early summer due to changes in the soil temperature may not at first be apparent, nor can one be assigned with any degree of assurance until we have obtained satisfactory continuous records of soil temperature at various depths below the surface. Still, observations do show that the temperature does progress downward slowly, and while the surface soil is so full of water, which is being evaporated from the surface rapidly, there would be relatively less energy left daily for transmission downward. Besides this, the zone of soil in which diurnal oscillations are appreciable, we have reason to expect is progressively increasing during the whole season of increasing temperature, and future continuous records may show that below even a very shallow depth there are, early in the summer, no measurable oscillations of this character.

There is another possible cause of increasing diurnal oscillations later in the season which does not exist in the spring. I refer to the extension and occupancy of the soil by the roots of growing vegetation. Since large volumes of water are carried to the surface in increasing quantities as the season advances, and since sap from the stems and leaves bathed in the warm air is carried downward into the ground to feed the roots, we may expect a certain quantity of heat to be transported below the surface and to considerable depths in this manner, and this would have an increasing effectiveness later in the season as the water is withdrawn from the soil, for such withdrawal must very materially diminish the mean specific heat of the soil, thus allowing the same number of heat units to produce a greater change in temperature.

EFFECT OF INCREASING SOIL TEMPERATURE ON THE GENERAL HEIGHT OF THE GROUND-WATER SURFACE.

Since the water-holding power of soil is decreased by an increase of temperature it follows that the seasonal rise of temperature in the ground must have the effect of increasing the rate of percolation and of enabling some water to reach the ground-water level which, during the earlier season, would be retained in the soil by capillary action. This effect, therefore, must tend to hold the level of ground-water above what it would otherwise occupy. The same cause would also tend to decrease the per cent. of water in the soil below the surface and cause it to appear to be drying out by capillary action upward, when in reality the drying was the result of percolation downward, due to a rise in the soil temperature.

INFLUENCE OF CHANGES IN SOIL TEMPERATURE ON UNDERGROUND DRAINAGE.

If it is admitted that an increase in soil temperature decreases the water-holding power of the soil, it should be expected that under suitable conditions drains should show a diurnal variation in the rate of discharge, due to diurnal changes of temperature. The curve produced by the drain gauge, which is shown in the figure, with those of the wells exhibiting the marked diurnal oscillations, appears to be in perfect accord with them so far as the diurnal oscillations are concerned, and hence indicates that there are or may be diurnal changes in the rate of flow of water from the ground, due to temperature changes.

During some laboratory studies conducted at this station, in which the writer attempted to ascertain whether the presence or absence of salts influenced the rate of flow of water through soil, he found that the apparatus was so extremely sensitive to temperature changes that no concordant results could be obtained until the whole apparatus was put under complete control so far as changes in temperature were concerned. To illustrate this influence the following results may be cited: Starting with the apparatus filled with a coarse sand and at a temperature of 9.01° C., the flow = 6.153 grams per minute; at 9.23° C., the flow = 6.27 grams per minute; at 9.38° C., the flow = 6.384 grams per minute; at 12.6° C., the flow = 7.046 grams per minute; at 23.8° C., the flow = 9.014 grams per minute; at 32.46° C., the flow = 10.54 grams per minute.

While it is likely that a part of the increase in the rate of flow through this sand was due to the fact that the coefficient of expansion of the walls of the apparatus and that of the sand were not the same, yet the differences in the rate are too large to be accounted for completely in this manner.

In case it is true that changes in the temperature of soil do affect the rate of flow of water through it, it should be expected that the configuration of the general ground-water surface would change as a consequence of this temperature influence, for under the lower grounds, where the summer temperature penetrates more quickly to the zone in which the water is flowing toward drainage outlets, the resistance to flow would be decreased and the surface of ground-water would fall more rapidly as a consequence than it would under the higher and colder ground.

Then, again, under the reverse conditions of winter, when the low lands are colder at the level of ground-water than under the higher land, the resistance to flow would be increased and the relatively more rapid drainage from the higher lands would tend to raise the water surface under the colder low lands above the normal, and hence to develop, toward spring, an attitude of the ground-water surface approaching more nearly to horizontality than is normal to the summer season.

We have shown that the diurnal variation in the temperature of the soil at a depth of 18 inches below the surface is, at the date of writing, only about 1° F., and that it is probably less than this at the depths of the wells and drains, and yet the continuous records obtained appear to show that such small changes of temperature are effective in modifying the rate of discharge of water into the drains as well as upon the height of water in the non-capillary spaces of the soil. Now, if the movements of water through the soil are thus sensitive to temperature changes it follows that in two countries where the mean soil temperatures vary to a considerable extent, the effectiveness, capacity, proper depth, and distance apart of tile drains may be found to materially differ.

TEMPERATURE TIDE OF THE GROUND-WATER SURFACE.

It follows, from the observations here recorded, that in all places where the diurnal oscillations of soil temperature reach the ground-water this surface is by it subjected to an ebb and flow vertically over the surfaces of the soil grains, which reaches upward possibly even through the zone of soil containing only hygroscopic moisture; for if the thickness of the film of water which can be borne by the soil grains varies with the temperature, there may be a progressive thinning and thickening of this film as the temperature rises and falls, and, if this is true, the soil grains are subjected to an exchange of water upon their surfaces throughout a deep zone, which must influence greatly those disintegration processes which contribute so much to the fertility of soils and to the leaching of them. Even if this ebb and flow is confined to a zone extending but a foot above the level where the non-capillary spaces in the soil remain full, the sum total of its effects must still be very great.

SEISMIC OSCILLATIONS OF THE GROUND-WATER SURFACE.

One of the surprising observations made during this study is that a heavily loaded moving train has the power of disturbing the level of water in the non-capillary spaces of the soil, but in just what manner this is brought about is not easy to see. The observed facts are these: While the self-registering instrument was upon well 48 it was

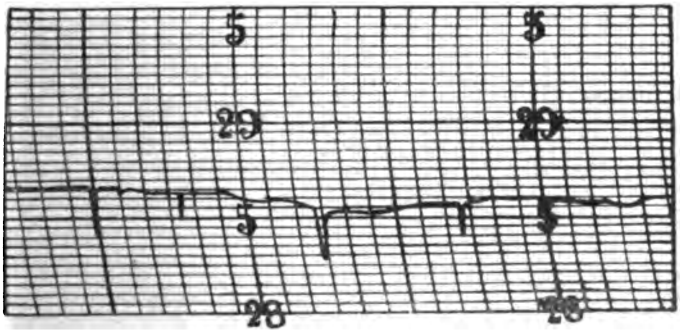

FIG. 36. Changes in level of water in well produced by moving train.

observed that there were frequent records of sharp, short period curves shown upon the sheet, which at first were supposed to be the result of accidental jars which the instrument sustained; but the frequency of their occurrence, and the fact that they were always dependent from the other curve, led to a closer scrutiny of them and their final association with the movement of trains past the well. On the eight-day instrument these fluctuations were shown as single dashes, but with the one-day form the curve was open and having the character shown in the tracing, Fig. 36. The well in which these disturbances occur is situated about 140 feet from the railroad track, and has a depth of 40 feet. It is tubed up with 6-inch iron pipe to the sandstone, 37 feet below the surface, and the water has a mean depth of about 20 feet in it.

The strongest rises in the level of the water are produced by the heavily loaded trains which move rather slowly. A single engine has never been observed to leave a record, and the rapidly moving passenger trains produce only a slight movement, or none at all, which is recorded by the instrument. The figure shows the curve to be produced by a rapid but gradual rise of the water, which is followed by only a slightly less rapid fall again to the normal level, there being nothing oscillatory in character indicated by any of the tracings nor observable to the eye when watching the pen while in motion. The downward movement of the pen usually begins when the engine has passed the well by four or five lengths, and when the pen is watched it may be seen to start and to descend quite gradually, occupying some seconds in the descent. The actual amplitude is one-third of that shown in the cut, which represents about the average occurrences, and these disturbances are not peculiarities of the present season when the ground-water surface occupies a higher plane than it has during the three years past, for the records of last year, which were procured with the improvised instrument to which reference has been made, bear evidence of the same disturbances produced then.

The manner in which a train moving across the ground-water surface lying seventeen to twenty feet below can effect such changes as the instruments have recorded is not at once apparent, especially when it is observed that the site of the records is 140 feet distant from the railroad track. The first explanation which suggests itself is that the short period shocks which the earth sustains in the transit of the train are transformed into a wave of long period which is propagated radially from the center of the disturbance and, reaching the well in its course, produces the record there obtained; but such an explanation appears to be rendered inadmissible because there is one single rise and fall, with no trace whatever in the curve of a repetition, as a true wave implies. A more probable hypothesis perhaps is that the mass of the train in its transit by the well depresses the earth bodily, causing it to sink into the ground-water more deeply and thus displace it laterally, causing it to rise under the surrounding area; but if this is true, and the displacement of the water has occurred equally in all directions, a rise of one-tenth of an inch at the well, 140 feet distant, means a downward displacement at the track amounting to something more than this, apparently twice that amount at least.

So far as the character of the curve and the method of recording it are concerned it would be equally admissible to suppose that the ground, as far away as the location of the instrument, was bodily depressed so that the recording apparatus moved downward, rather than that the surface of the water in the well moved upward, in producing the curve; but on this hypothesis the amount of earth moved seems enormously great when compared with the inertia of the train which produced the rise of water in the well. Again, it may be urged that the movement at the well which produced the record was the result of an upward thrust of the ground-water surface and a downthrow of the soil in the same place, so that the total movement in either case may not have exceeded .05 of an inch.

As still another alternative, it may be urged, that, either by compression of the zone of capillarily saturated soil lying just above the ground-water surface, or by its frequent recoils from the shocks imparted by the moving train, some of the capillary water is forced out of the soil and made to raise the mean level of the ground-water, thus augmenting the head so as to cause the water to rise in the well. But to raise a float one-tenth of an inch at a distance of 140 feet implies a dislodgement of capillary water and an augmentation of head seemingly too large to be produced by the most heavily loaded train.

Since such changes as result from the movement of a train over the ground affect the level of the water in it to such an extent as to be susceptible of measurement in the manner described, we may, perhaps, expect to find that the ground-water is sensitive to seismic disturbances and that the method here used, or a modification of it, is capable of rendering valuable information in volcanic districts regarding earth-tremors due to such causes. Indeed, the extreme complexity of some of the curves obtained here, and more especially of those obtained at Whitewater, of which tracings are given, implies, either that the barometric oscillations are much more frequent and of wider amplitude than we are accustomed to think, or else that the earth here is subject to tremors which may be recorded by fluctuations in the changes of level in the ground-water surface.

THE MECHANICAL ACTION OF BAROMETRIC CHANGES IN PRODUCING FLUCTUATIONS IN THE LEVEL AND DRAINAGE OF GROUND-WATER.

The evidence now at hand is insufficient to show, in a satisfactory and conclusive manner, just how changes in atmospheric pressure produce those changes in the level of the water in wells and in the rate of flow from the ground which have been shown to be closely associated with them. Unless some overshadowing influence is in operation at the same time, a rise in the barometer is very nearly coincident in time with a fall of the water in wells and with a diminished rate of discharge of water from the ground, and *vice versa*.

There are two radically different methods of action, by either of which we may suppose the phenomena in question are brought about through changes in atmospheric pressure. In the first place, it may be supposed that the general level of the ground-water surface is depressed or elevated bodily, as the case may be, by barometric changes, the loading of air upon a region depressing the ground-water surface of that region and the unloading of it permitting the level to be partly or wholly restored again. In the second place, it may be supposed that, through an unequal permeability of the soil above standing water in the ground, the changes in atmospheric pressure are more quickly felt by the water surface at some points than at others, and, as a consequence, a rising barometer will cause the water to be depressed in wells and in open soils, the water rising into both the capillary and non-capillary spaces of the adjacent less permeable areas, while a reduced air pressure would permit the confined air in the soil of the more impermeable regions to react and force the water into wells and drains, thus producing the phenomena associated with a falling barometer.

If a high barometric area develops over the west Atlantic Ocean while a low area has formed upon the eastern portion, maintaining a difference of pressure of one inch, the ocean surface, as a result of this unequal loading, will be deformed to the extent of 1.13 foot, the water-level on the west falling, while that upon the east rises through one-half of this distance; so if we suppose a continental ground-water surface in a state of drainage equilibrium to be similarly circumstanced, its surface would be, in a like manner, deformed, and as a result of this deformation, the water would stand higher in the wells and discharge more rapidly from the springs and drains of the low-pressure area while the converse would be true under the high area.

*If Mr. G. H. Darwin is right in his estimate, that if the barometer rises an inch over an area like Australia the load is sufficient to sink the continent two or three inches, and that the tides, which, twice a day, load the shores of the Atlantic, may cause the land to rise and fall as much as five inches, there appears no physical reason why, the ground-water surface being more mobile than the rigid earth, and at the same time capable of moving through its interstices, should not

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* Nature, Vol. XVI, page 367.

suffer a deformation greater than that of the land itself when subjected to a similar load. If a horizontal canal be conceived to span a distance of two thousand miles and to lie above the general drainage plane so that water might discharge from opposite ends through gates of equal capacity, it is evident that, were a low barometric area to rest upon one end, the water would discharge from that gate at a rate exceeding the average while at the opposite gate the rate of discharge would be less than the mean. In a like manner, if it is possible for atmospheric changes to depress or raise the ground-water surface in the vicinity of a system of tile drains, the water would flow more or less rapidly from this system according as the region was under the influence of a high or low barometric pressure.

It has been shown on a preceding page that the mean fall of the ground-water surface during times of rising barometer, as estimated by changes of level in wells, was .224 inch daily, while during times of falling barometer the mean fall was only .001 inch per day. Such a relation as this should be expected to exist if barometric changes are capable of affecting the general level of ground-water in the manner here under consideration. Then, again, in the case of the well in the galvanized iron cylinder, Fig. 31, in which the influence of temperature changes was shown, but which was constructed for the purpose of ascertaining whether or not the barometric changes were thus local in their effects, the curves nowhere show changes which can be ascribed to barometric influence, and this is what should be expected if the fluctuations are due to oscillations of the general ground-water surface. It is evident, however, that neither of these facts can be cited as lending much support to the view.

Turning now to the second hypothesis, the following conditions furnish the foundation for it: The condensation capacity of water for air varies with the pressure to which it is subjected, and, this being true, atmospheric changes are capable of affecting the volume of free air in the soil. It has been shown elsewhere in this paper that saturated and nearly saturated soils, especially those of fine texture, are nearly or quite impermeable to air under atmospheric changes of .1 of an inch. The capillarily saturated soils under field conditions possess both capillary and non-capillary spaces which contain air.

Under these conditions it may be assumed that when an area of low barometer passes upon a given district the equilibrium between the confined gases and capillary tension is destroyed, and by the expansion of the air escaping from the water and that which exists in the capillary and non-capillary spaces of the soil above the ground-water level capillary water is forced out into the wells and into drainage channels, and thus increases the underground drainage for the time and the height of water in wells and in soils to which the air has free access. Then, when the barometric conditions are reversed, the permanent rarefaction which the soil-air has sustained through the withdrawal of water, and air as well, from the interstices of the more impermeable soil permits the increased barometric pressure to force the water from the well back into the passageways from which it came and thus lower the water-level in the well; then, too, in the case of springs and drains, if the water is flowing from more or less impermeable beds an increase of pressure would increase the resistance against which the water was flowing from the soil, while a decrease of pressure would amount to the same thing as giving the water a steeper gradient.

This hypothesis appears much more applicable to the very short period fluctuation, which the records so often show, than it does to those which are more gradual and involve the movement of so much larger volumes of water, as in the case of the spring at Whitewater, which continued to flow under an increased head for days in succession with a falling barometer, producing a curve very nearly concentric with that of the barometer as far distant as Madison. It should be stated also in this connection that the barometric change of level in wells bears no definite relation to the diameter of the well into which the water percolates, the rise being very nearly or quite as great in a well 4 feet in diameter as it is in one 5 inches in diameter, and yet it would seem that, if the water is drained out of the soil locally, the larger the well the slower its level should change. This difficulty may perhaps be satisfactorily met by supposing that the positive or negative gaseous tension reacts vertically chiefly upon the general ground-water surface, causing it to rise and fall in a considerable measure bodily.

CAUSE OF TEMPERATURE OSCILLATIONS IN THE LEVEL OF GROUND WATER.

The amount of water which has been shown to leave the capillary spaces of the soil with an increase of temperature, and to return to them again when the changes are reversed, is so great as to make it difficult to understand how a simple diminution of the surface tension of the soil-water is capable of producing the whole movement, and has led the writer to suspect that possibly the expansion of the soil air contained in the capillary spaces of the soil, which is very nearly saturated, may, by its change of volume with change of temperature, account for a portion of the changes observed.

INSTANTANEOUS PERCOLATION AFTER RAINS.

It has been mentioned, in referring to the laboratory experiment relating to the distribution of capillary water in long columns of soil, that upon adding water to a column of coarse saturated sand, but which had ceased to percolate, the water began flowing again as soon as more was added to the surface. In this case the water which percolated at first was not that added to the surface, as was proven by the fact that in a short time the percolation ceased but only to begin again several hours later. The same fact I have observed in the field, and in Fig. 37 are produced the curves obtained with three of the self-recording instruments at one of these times; two of them on wells and one upon a drain. On the morning of July 24 a sudden shower came from the north of west, and just as the black clouds were approaching, apparently about 20° above the horizon, the barometer began suddenly to rise and continued to do so until a few minutes after the rain began, when it fell almost as suddenly to .05 of an inch below the starting point. On going to the wells and drain in less than 10 minutes after the shower of 15 minutes' duration had ceased, I found that the water had raised and was flowing so much more rapidly from the drain as to oblige the pen to be reset. The curve from the drain shows very conclusively that an increase in the discharge had occurred which persisted after the barometric change had passed.

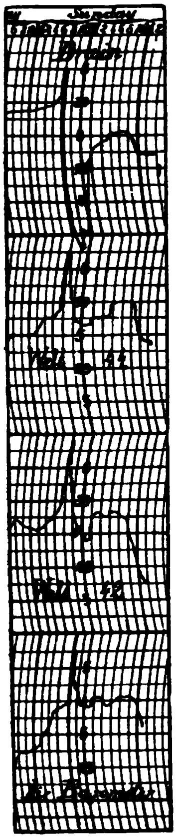

FIG. 37. Curves due to instantaneous percolations after rains.

These cases of sudden percolation I believe to be due to hydrostatic pressure which the water, falling upon the surface so rapidly as to close the air passages, exerted through the soil air upon the ground-water below.

PERCOLATION THROUGH FROZEN GROUND.

There appears to be a quite general impression that while the ground is frozen there can be little or no percolation through it. This is so far from being true that, during three consecutive winters, at times of sudden thaws or winter rains which melted considerable snow, the system of drains on the Experiment Station farm has discharged water so rapidly into the big silt well, No. 25, Fig. 3, that a 6-inch tile drain 560 feet long was only able to carry away the water brought to it when it had a fall of over 2 feet and a head in the well of nearly 4 feet. Not only has the water been observed to find its way into the drains through the frozen ground, but also into the shallow wells. During these times the water appears to find its way into the ground through shrinkage cracks, through perforations made by earth worms, and does so without apparently contributing very much to the surface 3 feet of soil. These facts are significant in the bearing they have upon the practice, now coming to be so general, of spreading farmyard manure upon the field during the winter. I would not here urge that these observations should disparage the practice, but that the matter is one which merits careful consideration in the study of the advantages of winter manuring.

SOME DIRECTIONS IN WHICH FURTHER STUDY IS NEEDED.

It should be at once apparent, in a subject possessing the extreme complexity of the one under consideration and presenting so many aspects of economic and scientific interest as does the movement of rain after it has penetrated the ground, that the observations herein presented can only be regarded as of the nature of a preliminary reconnoissance of but a small portion of a field in which our exact knowledge is relatively very limited.

A careful and detailed study of the movements of ground-water ought to supply very important knowledge bearing upon the contamination of drinking waters and the spreading of certain classes of contagious diseases, and thus help to place the water supply for both urban and rural purposes under better sanitary conditions.

Every advance which is made toward the increase of yield per acre necessarily means an increased demand for water, so that market gardeners even in Wisconsin and Illinois, where both the annual and summer rainfall is relatively large, are turning their attention toward providing suitable means for irrigation; and a rapid and economical advance in this direction demands a much more thorough knowledge of the movements of underground water than we at present possess.

In the utilization of natural subirrigation, to which reference has been made, and in the reclaiming of swamp lands for agricultural purposes, which must be of growing importance in the immediate future, there is imminent need for new knowledge in the same direction.

Before we can understand the full significance and extent of the movements of underground water, it will be necessary to have synchronous observations covering, not only considerable intervals of time, but also extended areas as well, and valuable contributions to our knowledge should be expected if improved forms of self-registering apparatus for recording the changes in the level of ground-water were to be set up at many meteorological and experiment stations; and since the soil-water has been shown to be so susceptible to movements resulting from small barometric and temperature changes, there should be forms of self-recording soil-thermometers more sensitive than any now available, and barographs which are capable of recording much smaller changes of pressure than most existing instruments do. It may be that a barograph constructed on the principle of the air barometer described in Fig. 23, but using a fixed oil instead of water, filling the chamber with chemically dry air and burying the whole more deeply in the ground, where the diurnal changes of temperature would always be very small, would answer the needs of such a study.

If the movements of ground water generally even approximate those which the observations here recorded appear to indicate, a fuller understanding of them must shed much light upon those metasomatic changes which are of such great importance in geologic processes and in the origin and formation of metalliferous deposits.

Then again, if tidal fluctuations do really exist in the ground-water, as Mr. Roberts has affirmed, and if it is sensitive to seismic disturbances, as the observations here recorded in regard to the moving train suggest, a study of the movements of ground water may be expected to contribute much toward an understanding of the nature, extent, and effects of the movements of the solid portions of the earth, whether they are due to stresses originating in extra-terrestrial causes or geologic or meteorologic shiftings of load upon the earth's surface.

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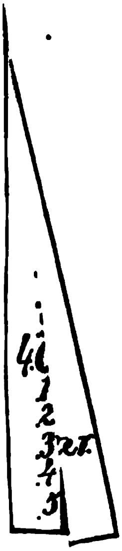
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U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 6.

THE DIURNAL VARIATION OF BAROMETRIC PRESSURE.

BY

FRANK N. COLE, PH. D.,
ASSISTANT PROFESSOR OF MATHEMATICS, UNIVERSITY OF MICHIGAN.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
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1892.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., October 4, 1892.

SIR: I have the honor to transmit herewith a paper entitled "The Diurnal Variation of Barometric Pressure," which has been prepared by Dr. Frank N. Cole, and to recommend its publication as Weather Bureau Bulletin No. 6.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. J. M. RUSK,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

University of Michigan,
Ann Arbor, Mich., July 26, 1892.

Sir: I have the honor to submit herewith my Report on the Diurnal Variation of Barometric Pressure.

Very respectfully,

Frank N. Cole.

Mark W. Harrington,
Chief of Weather Bureau.

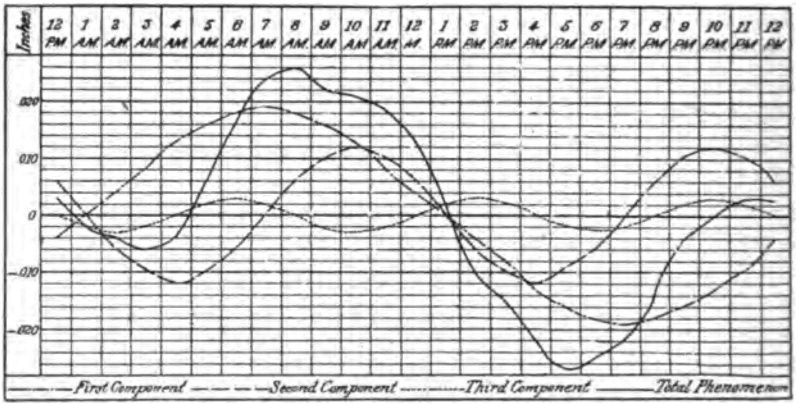
THE DIURNAL VARIATION OF BAROMETRIC PRESSURE.

The daily variation of atmospheric pressure on the earth's surface is one of the most regular of atmospheric phenomena. As is well known, the barometric oscillation attains, except in a few localities, two maxima and two minima every twenty-four hours, the minima occurring between 2 and 4 o'clock of the early morning and afternoon, and maxima between 8 and 11 of the forenoon and evening. On the open sea in the tropics, where the disturbing effect of a land surface is eliminated and the daily variation in temperature reduced to a minimum, the barometric curve is almost perfectly symmetrical, presenting nearly equal maxima and minima at equal intervals of six hours. On land, however, and particularly in the interior of continents, the symmetry is considerably diminished, the maxima and minima are no longer equal, the day variation exceeds that of the night, and the intervals between the maxima and minima differ measurably.

Despite the regular character of the phenomenon, the determination of the physical causes producing it presents a problem of extreme difficulty. If the older method of regarding the barometric oscillation as a single phenomenon is adopted, it seems at first sight possible to account for the afternoon minimum as a direct result of the temperature maximum preceding it by one to two hours, and the consequent ascent of the heated atmosphere. Similarly, the morning maximum might be connected with the early morning temperature minimum, although obvious difficulties at once present themselves here. But it is an insurmountable objection to the theory that it can neither account for the night variation nor for that on the ocean surface in the tropics, which goes on with undiminished amplitude under a daily range of temperature of only two or three degrees.

On the other hand the method of harmonic analysis, *i. e.*, the resolution of the barometric oscillation into its harmonic constituents, promises material assistance in the solution of the problem of the physical cause. It is found that the barometric oscillation consists in the main of two components with periods of 24 and of 12 hours, respectively. Of these, the daily component is decidedly irregular in both phase and amplitude, and is undoubtedly due, at least in a large part, to local conditions. It nearly disappears on the tropical ocean, but occurs everywhere on the land with a large amplitude, which increases toward the centers of the continents and attains its maximum values in mountain valleys. The second (bi-daily) component, on the contrary, presents the utmost regularity in both phase and amplitude. It is apparently entirely independent of local conditions taking place over the entire earth, at least as far as latitude 60°, with a nearly mathematically uniform phase and a constant amplitude diminishing slowly as the latitude increases. Besides these two components there are others of higher orders, which, however, constitute only a very small part (in the mean perhaps one-eighth) of the whole. Of these, the third component (period 8 hours) seems from its regular character to represent a physical reality. Whether this is true of the others remains to be established.

The accompanying figure represents the first three component curves of barometric pressure, together with the actual barometric curve, for New York City for the month of June for the four years 1888–1891. The amplitudes of the first three components in inches are .019, .012, .003; their first maxima occur at, approximately, 7 a. m., 10 a. m., and 6 a. m.



Component curves of barometric pressure, New York City.

It is a fundamental question whether the process of harmonic analysis, as applied to the barometric variation, has an actual physical meaning. The component oscillations are usually computed from monthly means, any temporary irregularities thus disappearing in the mean. It may be observed that all those variations which have the same period, and only those, will be collected in the analysis into a single component, and that there is no method at present applicable for the separation of a component into further parts.

It seems to be generally agreed among meteorologists that the first (daily) and second (bi-daily) components are physical realities due
ct causes. The first component is certainly due to such daily
s the variation in temperature with its single maximum, land

and sea breezes, precipitation, frost, dew, and the general daily phenomena which are connected with the topography of the particular region.

The second component is an entirely different matter. We have here an oscillation with a period of 12 hours nearly uniform over the entire globe as far as latitude 60°, with a phase which moves with the greatest regularity forward in summer and backward in winter, through a range of about an hour. It is in form a perfect analogy to the solar tide. But it is, of course, impossible to suppose with some of the early meteorologists, that it is in any way gravitational. It is believed by Hann and other eminent authorities to be due, in some not as yet wholly determined way, to the sun's radiant energy absorbed in the upper atmosphere. Hann has shown that the amplitude of this component, at least in the lower latitudes, has a maximum in December corresponding to the earth's perihelion. The difficulty with the component is, of course, to account for the night maximum and minimum. One cannot avoid recurring again and again to its tidal character. It has even been suggested that it is of cosmical origin, perhaps due to electro-magnetic causes.

If we accept the second component as physical, it is difficult to reject the higher components. Nevertheless, a natural hesitation is felt in supposing oscillations with periods of $\frac{24}{4}$, $\frac{24}{5}$, etc., hours to have a real existence. Mathematically, these periods are present to several higher orders, in winter perhaps seven or eight. The only criteria available for distinguishing the real from the imaginary components are the regularity of the former and their coincidence with other physical phenomena. From this standpoint the third component must certainly be regarded as real. This component resembles greatly the second. Although very small in the mean, it is extremely regular and uniform over the whole earth. Its amplitude has a minimum at each equinox, a large maximum in winter and a smaller one in summer. Besides this, the third component reverses its phase at the equinoxes, *i. e.*, its maxima in summer fall at the hours of the minima in winter. It seems certain that this component is connected in some way with the annual march of the sun, and is of the same general character as the second in regard to its moving cause.

The fourth component also shows a very noticeable regularity in both amplitude and phase, although much less so than the third. This component has a nearly constant amplitude from the vernal to the autumnal equinox, increasing about threefold in winter. The rapid and considerable change of its phase from month to month, while proceeding with great uniformity over the earth, makes it difficult to determine in many cases whether the change is a progression or a regression, and the difficulty is increased by the smallness of the amplitude in summer, which may decidedly affect the accuracy of the calculation of the phase. A satisfactory treatment of the fourth component would require its determination for smaller intervals than a month. Probably fifteen days would be a convenient interval. From the data available it would seem that the fourth component is, like the preceding ones, a physical reality.

Tables I to VI give the amplitudes and phases of the first four components of barometric pressure computed from the monthly means for periods of two to four years, ending December 31, 1891, for the six cities, Boston, New York, Philadelphia, Chicago, Saint Louis, and Denver. To these are added the averages for Greenwich, England, for the 20 years, 1854 to 1873.*

NOTE ON THE METHOD EMPLOYED IN THE COMPUTATION OF THE HARMONIC COMPONENTS.

The computations follow the method given by Strachey in the proceedings of the Royal Society of London, vol. 42, p. 61, except that I find it more convenient to use the form

$$P_1 \cos. (x - \mu_1) + P_2 \cos. (2x - 2\mu_2) + P_3 \cos. (3x - 3\mu_3) + \ldots\ldots$$

than the form

$$P_1 \sin. (x - A_1) + P_2 \sin. (2x - A_2) + P_3 \sin. (3x - A_3) + \ldots\ldots$$

Otherwise my tables are precisely like those of Strachey, as given on pp. 75 and 77 of the article referred to.

In some cases it is impossible to decide whether the phase has moved forward or backward. These cases are marked with an *. The mean barometer is noted for each month, except in the case of Chicago, where the location of the station was changed in 1890.

The computations in Table I are for standard time; to reduce to local time add 4° to each angle. Tables II to VI are computed for local time.

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* Taken from the British report on Harmonic Analysis of Temperature and Pressure at British observatories. London, 1891.

TABLE I.—*Harmonic analysis for pressure.*

BAROGRAPH READINGS, BOSTON, MASS. SUMMARY, 1888-1891.

	Year.	P_1	P_2	P_3	P_4	μ_1	μ_2	μ_3	μ_4
						° ′	° ′	° ′	° ′
January, 29.9165.........	1889.....	.0101	.0021	.0017	.0007	124 06	109 20	5 25	35 36
	1890.....	.0236	.0174	.0075	.0045	37 29	135 06	30 00	64 21
	1891.....	.0090	.0090	.0073	.0044	28 27	135 59	27 28	50 16
	Mean...	.0142	.0111	.0055	.0032	63 21	126 48	20 58	50 04
February, 29.9350.........	1889. ...	.0090	.0019	.0014	.0007	107 30	140 03	2 43	75 45
	1890.....	.0114	.0149	.0066	.0009	6 38	131 00	27 34	77 58
	1891.....	.0106	.0153	.0046	.0005	65 02	136 45	31 09	67 30
	Mean...	.0103	.0107	.0042	.0007	59 43	135 56	20 29	73 44
March, 29.8471............	1889.....	.0107	.0011	.0010	.0005	127 01	136 41	5 42	— 2 03
	1890.....	.0278	.0188	.0026	.0007	59 08	137 39	19 46	10 13
	1891.....	.0152	.0174	.0014	.0013	99 13	133 34	15 00	12 48
	Mean...	.0179	.0124	.0017	.0008	95 07	135 58	13 29	6 59*
April, 29.8831............	1888.....	.0163	.0106	.0014	.0024	67 36	135 11	30 00	19 11
	1889.....	.0117	.0078	.0008	.0007	82 52	138 12	75 00	17 14
	1890.....	.0194	.0182	.0019	.0017	87 29	139 46	95 01	8 46
	1891.....	.0178	.0158	.0023	.0028	31 06	140 38	105 50	23 46
	Mean...	.0163	.0131	.0016	.0019	67 16	138 27	76 28	16 74
May, 29.8499.............	1888.....	.0136	.0133	.0012	.0010	66 33	149 31	94 41	6 35
	1889.....	.0183	.0133	.0026	.0004	93 18	130 14	67 44	22 30
	1890.....	.0253	.0149	.0026	.0013	76 11	141 14	95 40	8 10
	1891.....	.0273	.0149	.0017	.0007	74 43	139 07	91 35	33 54
	Mean...	.0211	.0141	.0020	.0008	77 41	140 01	87 25	17 47
June, 29.8074............	1888.....	.0188	.0117	.0020	.0005	86 10	145 56	84 41	12 16
	1889†....	.0250	.0119	.0033	.0004	87 35	136 17	81 19	—28 29*
	1890.....	.0178	.0100	.0033	.0006	82 34	140 59	90 48	1 49
	1891.....	.0196	.0108	.0024	.0011	103 23	144 13	91 38	16 15
	Mean...	.0203	.0111	.0027	.0006	89 55	141 51	87 06	2 58
July, 29.8693.............	1888.....	.0161	.0100	.0005	.0009	103 11	142 09	62 22	2 11
	1890.....	.0171	.0117	.0034	.0006	80 15	139 45	89 37	18 00
	1891.....	.0107	.0092	.0013	.0007	108 13	141 28	77 55	6 55
	Mean...	.0146	.0103	.0018	.0007	97 13	141 07	76 38	9 02
August, 29.8687..........	1888.....	.0088	.0122	.0010	.0016	85 16	139 55	82 59	— 2 31
	1889‡....	.0107	.0119	.0018	.0007	91 51	142 10	90 44	— 8 10
	1890.....	.0056	.0110	.0026	.0005	85 18	138 19	80 01	10 58
	1891.....	.0137	.0110	.0017	.0001	107 23	141 20	93 55	0 00
	Mean...	.0097	.0115	.0018	.0007	92 27	140 26	86 55	0 04*
September, 29.9596......	1888.....	.0132	.0109	.0003	.0008	20 25	134 28	21 09	23 37
	1889.....	.0080	.0127	.0010	.0010	78 02	137 43	17 59	15 48
	1890.....	.0133	.0141	.0012	.0006	79 45	139 16	6 51	9 52
	1891.....	.0184	.0167	.0008	.0007	93 41	141 42	28 16	4 46
	Mean...	.0132	.0136	.0008	.0008	68 03	138 17	18 34	13 31
October, 29.8301.........	1888.....	.0127	.0166	.0032	.0001	29 54	125 42	8 07	22 30
	1889.....	.0097	.0149	.0023	.0008	52 52	131 38	12 31	48 43
	1890.....	.0048	.0152	.0023	.0000	79 00	119 27	19 25	0 00
	1891.....	.0054	.0143	.0025	.0004	56 30	139 09	20 40	— 2 20
	Mean...	.0081	.0152	.0026	.0003	54 34	128 59	15 11	17 13*
November, 29.9417.......	1888.....	.0219	.0151	.0028	.0006	69 00	136 23	21 21	56 11
	1889.....	.0057	.0150	.0063	.0004	66 43	128 32	24 03	42 40
	1890.....	.0052	.0182	.0058	.0016	47 03	119 07	18 09	58 03
	1891.....	.0149	.0166	.0061	.0010	87 58	130 28	20 05	69 16
	Mean...	.0119	.0162	.0052	.0009	67 41	128 37	20 54	56 32
December, 29.9066.......	1888.....	.0126	.0130	.0066	.0020	43 44	129 20	24 18	51 36
	1889.....	.0124	.0107	.0066	.0051	36 59	124 02	24 09	53 07
	1890.....	.0078	.0152	.0070	.0031	167 50	129 09	22 00	55 06
	1891.....	.0103	.0141	.0094	.0043	115 50	127 19	21 27	53 26
	Mean...	.0123	.0147	.0074	.0036	91 06	127 27	22 59	53 19
4 years, 29.8845.........	....	.0142	.0128	.0031	.0012	77 01	135 19	45 35	26 32

† 1-18. ‡ 10-31.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 6.

THE DIURNAL VARIATION OF BAROMETRIC PRESSURE.

BY

FRANK N. COLE, PH. D.,
Assistant Professor of Mathematics, University of Michigan.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
1892.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., October 4, 1892.

SIR: I have the honor to transmit herewith a paper entitled "The Diurnal Variation of Barometric Pressure," which has been prepared by Dr. Frank N. Cole, and to recommend its publication as Weather Bureau Bulletin No. 6.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. J. M. RUSK,
Secretary of Agriculture.

TABLE VI.—*Harmonic analysis for pressure.*

BAROGRAPH READINGS, DENVER, COLO. SUMMARY, 1889–1891.

	Year.	P_1	P_2	P_3	P_4	μ_1	μ_2	μ_3	μ_4
						° ′	° ′	° ′	° ′
January, 24.7216	1890	.0065	.0172	.0078	.0053	77 42	142 25	27 05	57 16
	1891	.0045	.0149	.0038	.0052	70 29	146 17	33 30	61 11
	Mean	.0055	.0160	.0058	.0052	74 05	144 21	30 18	59 13
February, 24.6004	1890	.0270	.0192	.0014	.0008	40 18	139 48	21 57	61 16
	1891	.0053	.0134	.0025	.0024	169 17	129 31	47 17	85 11
	Mean	.0161	.0163	.0034	.0016	89 47	134 39	34 37	73 13
March, 24.6625	1890	.0195	.0188	.0019	.0006	90 54	137 32	13 32	65 51
	1891	.0102	.0135	.0019	.0011	27 36	142 03	33 30	75 24
	Mean	.0178	.0161	.0019	.0008	59 15	139 47	23 31	70 37
April, 24.7490	1890	.0258	.0196	.0030	.0018	81 51	148 49	103 06	49 34
	1891	.0209	.0141	.0017	.0009	43 20	144 32	105 00	51 19
	Mean	.0233	.0168	.0023	.0013	62 35	146 40	104 03	50 26
May, 24.7442	1890	.0361	.0141	.0047	.0017	66 41	141 33	92 50	71 53
	1891	.0261	.0157	.0026	.0008	67 32	144 49	90 00	62 43
	Mean	.0311	.0149	.0036	.0012	67 05	143 11	91 25	67 18
June, 24.7211	1890	.0402	.0140	.0050	.0011	75 57	143 39	94 14	43 45
	1891	.0332	.0139	.0044	.0007	79 11	143 51	90 18	50 36
	Mean	.0367	.0139	.0047	.0009	77 34	143 45	92 16	47 10
July, 24.8553	1890	.0220	.0119	.0037	.0002	80 47	151 37	102 13	65 14
	1891	.0226	.0121	.0030	.0007	98 55	147 36	96 42	61 22
	Mean	.0223	.0120	.0033	.0004	89 51	149 36	99 27	63 18
August, 24.8687	1890	.0127	.0152	.0025	.0007	77 47*	146 12	101 58	55 02
	1891	.0115	.0153	.0007	.0014	83 20	146 51	105 00	61 30
	Mean	.0121	.0152	.0016	.0010	80 33	146 31	103 29	58 16
September, 24.8326	1889	.0295	.0127	.0010	.0019	81 52	138 32	63 46	58 54
	1890	.0240	.0107	.0011	.0006	82 25	145 30	110 19	60 00
	1891	.0261	.0196	.0014	.0012	84 07	147 23	67 37	52 08
	Mean	.0265	.0143	.0013	.0012	82 48	143 48	80 34	57 01
October, 24.8374	1889	.0201	.0138	.0012	.0021	85 39	135 21	19 28	53 54
	1890	.0230	.0153	.0008	.0026	68 09	136 16	73 44	51 27
	1891	.0271	.0220	.0042	.0016	61 57	139 44	36 20	55 58
	Mean	.0234	.0170	.0031	.0021	71 55	137 07	43 11	53 46
November, 24.8278	1889	.0116	.0126	.0050	.0015	62 56	130 06	18 54	48 37
	1890	.0132	.0127	.0016	.0021	55 58	137 40	16 44	63 19
	1891	.0120	.0192	.0061	.0021	16 06	142 15	32 48	61 56
	Mean	.0123	.0148	.0045	.0019	45 00	136 40	22 49	57 57
December, 24.7128	1889	.0116	.0169	.0052	.0045	54 08	128 13	19 33	52 36
	1890	.0120	.0159	.0051	.0036	58 07	140 08	30 00	60 00
	1891	.0132	.0180	.0081	.0038	300 32	138 57	31 08	67 23
	Mean	.0123	.0159	.0061	.0040	137 36	135 46	26 54	60 00

TABLE VII.—*Harmonic analysis for pressure.*

BAROGRAPH READINGS, GREENWICH, ENGLAND, 1854-1873.

Month.	P_1.	μ_1.	P_2.	μ_2.	P_3.	μ_3.	P_4.	μ_4.	Mean pressure P.
		°		°		°		°	
January	.0099	229	.0081	147	.0045	34	.0026	64	29.729
February	.0074	124	.0098	153	.0035	39	.0011	86	29.832
March	.0063	79	.0107	156	.0015	44	.0012	19	29.722
April	.0080	92	.0102	156	.0009	104	.0010	40	29.804
May	.0089	61	.0089	156	.0018	98	.0009	46	29.777
June	.0074	77	.0086	158	.0023	101	.0009	56	29.829
July	.0061	88	.0083	160	.0022	103	.0010	49	29.809
August	.0058	84	.0099	157	.0016	107	.0011	44	29.799
September	.0059	124	.0109	153	.0011	31	.0015	35	29.787
October	.0071	37	.0106	149	.0028	30	.0009	45	29.720
November	.0060	250	.0089	148	.0035	32	.0012	66	29.763
December	.0076	123	.0081	149	.0046	33	.0027	62	29.791
Mean for 20 years	.0072	114	.0094	154	.0025	63	.0013	51	29.780

NOTE.—The mean values of μ_1 are of doubtful accuracy, particularly for the months of January and November.

THE FIRST THREE COMPONENTS.

The phase of the first component exhibits a considerable degree of regularity. For 85 stations cited by Hann the maximum of the first component occurred at 61 between 4 a. m. and 8 a. m., and at 35 between 4 a. m. and 6 a. m., coinciding therefore, approximately, with the time of minimum temperature. For the 6 American stations tabulated above, excluding Denver, the extreme limits for the means are 3.48 a. m. and 8.40 a. m. If Chicago is omitted the upper limit reduces to 8 a. m. All the stations show a marked progression of the phase from winter to summer, possibly due to the forward motion of the epoch of maximum temperature. Undoubtedly the unsymmetrical form of the daily temperature curve and the approach and recession of its maximum and minimum have a powerful effect on the phase of the first barometric component. Great irregularities in the phase occur only in the winter months, when there is a decided tendency to a retrogression as far as midnight. The greatest deviation from the normal was in Denver in December, 1891, when the maximum occurred at 8 p. m. The twenty-year series for Greenwich show a much greater variation than those for the American stations, together with a retrogression of the phase in summer instead of a progression.

It is suggested by Hann that the first component may be in reality made up of two portions, one universal and resembling in this respect the second component, the other local. It should be possible to settle this question by a comparison of observations from a number of neighboring stations with as different local conditions as possible.

A comparison of the tables for Boston, New York, and Philadelphia furnishes interesting results in regard to the amplitude of the first component. The months of October, 1889, 1890, and 1891 show an amplitude much below the normal, preceded by a similar depression in August of 1890 and September of 1889. The depression continued in 1889 and 1890 through November, and in 1890 through December, and January of 1891. In the latter month it extended to New York and Philadelphia, and in February it had disappeared in all three cities. The remaining components were not affected during this time. A study of the local influences producing so considerable an effect would certainly repay the labor spent. It is from an examination of such abnormalities that the true causes of the normal phenomenon can be best determined.

The mean yearly amplitudes of the first component for the six American stations are: Boston, .0128; New York, .0165; Philadelphia, .0178; Chicago, .0157; Saint Louis, .0259; and Denver, .0200, increasing on the whole, as is seen, toward the interior of the continent. These amplitudes are remarkably larger than those for European stations: Greenwich, .0072; Paris, .0070; Leipzig, .0060; Vienna, .0081; Geneva, .0100, and approach the values characteristic of mountain regions.

Of the six American stations (excluding Denver on account of its elevation and surroundings), Saint Louis exhibits the greatest regularity, and Boston the greatest irregularity in respect to the amplitude of the first component. Boston, in fact, seems to be a border city, and it would be of great value to compare its first component for a series of years with that of Saint John or of Halifax.

The mean yearly range of the time of first maximum and the mean amplitude of the second component for each of the six stations and for Greenwich are given in the following table, the hours being all a. m.:

TABLE VIII.—*Mean annual amplitude and epoch of first component.*

Station.	μ_2	P_2
	Hours.	
Boston	8.40 to 9.40	.0128
New York	9.20 to 10.12	.0150
Philadelphia	9.24 to 10.12	.0166
Chicago	9.12 to 10.24	.0116
Saint Louis	9.28 to 10.16	.0154
Denver	8.56 to 9.56	.0153
Greenwich	9.48 to 10.40	.0094

The mean first maximum accordingly varies by almost exactly an hour in the course of the year for all the seven localities in entirely different situations and with considerable difference in climate; and the same regularity occurs in fact everywhere. As in the case of the first component the amplitude for Greenwich is much less than that for the American stations. This is, however, here due, in part, to the fact that the amplitude of the second component diminishes as the latitude increases over the whole earth. For Vienna, 3° south of Greenwich, the amplitude is .0122.

The following table shows the monthly means of the amplitude for the six stations:

TABLE IX.—*Mean monthly amplitude of first component.*

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Boston	.0111	.0107	.0124	.0131	.0141	.0111	.0103	.0115	.0136	.0152	.0162	.0147
New York	.0185	.0180	.0157	.0170	.0154	.0119	.0117	.0118	.0146	.0146	.0150	.0162
Philadelphia	.0191	.0181	.0181	.0178	.0163	.0142	.0125	.0141	.0158	.0176	.0176	.0176
Chicago	.0135	.0123	.0127	.0119	.0107	.0114	.0192	.0109	.0131	.0114	.0104	.0117
Saint Louis	.0149	.0175	.0188	.0162	.0132	.0132	.0133	.0150	.0160	.0158	.0140	.0162
Denver	.0160	.0163	.0161	.0168	.0149	.0139	.0120	.0152	.0143	.0170	.0148	.0159
Mean	.0155	.0155	.0156	.0155	.0141	.0126	.0115	.0131	.0146	.0153	.0147	.0154
Mean omitting Boston	.0164	.0164	.0163	.0160	.0141	.0129	.0117	.0134	.0148	.0153	.0143	.0153

The winter maximum and summer minimum discovered by Hann, and attributed by him to the earth's perihelion and aphelion, appear clearly in each of the cases as well as in the mean. The maxima at the equinoxes are also distinguishable, but are confused in the spring with the winter maximum. A mean is given at the foot of the table for five of the stations, Boston being excluded on account of the abnormal character of the amplitude for the first three months of 1889, when it sunk to $\frac{1}{5}-\frac{1}{10}$ of its normal value. So great an irregularity does not occur at any other of the six stations, not even at Denver, where the first component has an amplitude ranging from .005 to .037. The exceptional character of the barometric oscillation at Boston deserves, as already stated, a special investigation. It will be noticed in Table I that in the month referred to above the amplitudes of the second, third, and fourth components were all greatly reduced below the normal, and that none of these components were affected at New York.

The regular and universal march of the amplitude of the third component is shown in the following table:

TABLE X.—*Mean monthly amplitude of the third component.*

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Boston	.0055	.0042	.0017	.0016	.0020	.0027	.0018	.0018	.0008	.0026	.0052	.0074
New York	.0079	.0039	.0018	.0017	.0028	.0030	.0023	.0015	.0014	.0028	.0043	.0065
Philadelphia	.0079	.0045	.0015	.0019	.0023	.0026	.0021	.0018	.0010	.0028	.0057	.0069
Chicago	.0062	.0043	.0012	.0010	.0026	.0028	.0021	.0010	.0011	.0022	.0048	.0071
Saint Louis	.0070	.0057	.0015	.0018	.0028	.0029	.0024	.0017	.0009	.0036	.0058	.0074
Denver	.0058	.0034	.0019	.0023	.0036	.0047	.0033	.0016	.0013	.0031	.0045	.0061
Greenwich	.0045	.0035	.0015	.0009	.0018	.0023	.0022	.0016	.0011	.0028	.0035	.0046
Calcutta	.0077	.0055	.0020	.0019	.0041	.0038	.0035	.0032	.0007	.0030	.0052	.0073
Melbourne	.0050	.0026	.0009	.0028	.0055	.0059	.0054	.0053	.0030	.0002	.0030	.0040

In the northern hemisphere a large maximum occurs in December–January and a smaller one in May–June, while the reverse is the case in the southern. In all cases a strongly marked minimum occurs at each equinox. The amplitudes of the several stations show a most remarkable agreement, greater than that for the second component. A similar uniformity of phase appears in the annexed table for the first maximum (the hour is reckoned from local midnight).

TABLE XI.—*Epoch of the first maximum of third component.*

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	Hrs.	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*
Boston	1.40	1.38	1.10	5.22	6.06	6.04	5.22	6.09	1.29	1.16	1.40	1.48
New York	1.49	2.15	1.41	6.37	7.13	6.14	6.34	6.32	1.42	1.23	1.36	1.58
Philadelphia	2.16	2.16	1.16	5.36	6.46	6.22	7.16	5.58	3.19	1.43	1.53	2.16
Chicago	1.59	2.17	2.22	4.08	6.31	6.45	7.04	5.40	3.45	2.00	1.53	2.12
Saint Louis	2.23	2.20	3.20	5.04	6.30	6.48	6.05	5.33	2.26	2.04	2.11	2.02
Denver	2.01	2.18	1.34	6.57	6.06	6.09	6.38	6.54	5.22	2.53	1.31	1.48
Greenwich	2.16	2.36	2.56	6.56	6.32	6.44	6.52	7.08	2.04	2.00	2.08	2.12

It is seen at once that the epoch of the maximum is nearly constant between the equinoxes, but changes at the latter abruptly. The means for each station from October to February and from April to August are:

TABLE XII.—*Means from October to February and April to August.*

Station.	Oct. to Feb.	Apr. to Aug.	Difference.
	Hrs.	*Hrs.*	*Hrs.*
Boston	1.36	5.48	4.12
New York	1.48	6.38	3.50
Philadelphia	2.05	6.24	4.19
Chicago	2.04	6.01	3.57
Saint Louis	2.12	6.00	3.48
Denver	2.08	6.33	4.25
Greenwich	2.14	6.50	4.36
Mean	2.01	6.17	4.16

It appears that the third component with its period of eight hours changes its phase for all stations by almost exactly four hours at each equinox, in other words, that its phase is exactly reversed at these two points. In view of these facts it seems established that the third component is a direct result of the annual motion in latitude of the sun; that, representing this cause, it is complementary to the second component, the two together furnishing nearly the whole of that portion of the barometric oscillation which is due to universal, as distinguished from local, causes. The minima in the amplitude of the third component are evidently unreal. They appear in the monthly averages only on account of the reversal of phase, which must, of course, produce precisely this effect. In reality, the amplitude has one maximum in winter and one minimum in summer.

The determination of an adequate physical cause for the fourth component is a matter of much greater difficulty. Nevertheless, its amplitude and phase show a great uniformity. The amplitude is always a maximum in winter and diminishes rapidly to a fairly constant value, often approaching the vanishing point in summer. Its mean ratio to the amplitude of the second component is as follows, (yearly means): Boston, 12:31; New York, 15:33; Philadelphia, 14:34; Chicago, 14:30; Saint Louis, 18:36; Denver, 18:35; Greenwich, 13:25, *i. e.*, about 1:2. The epoch of the first (or second) maximum from month to month is:

TABLE XIII.—*Epoch of the first maximum.*

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	Hrs.	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*
Boston	3.36	5.11	6.44	7.41	7.21	6.28	6.52	6.16	7.06	7.25	4.02	3.49
New York	3.55	5.25	6.47	6.45	7.17	7.35	7.29	3.55	7.35	4.26	4.14	3.51
Philadelphia	4.01	4.21	7.02	8.19	6.39	5.18	6.19	7.57	7.58	8.30	4.00	4.01
Chicago	4.06	6.13	7.12	7.13	6.10	5.30	5.32	6.29	6.13	6.05	4.17	4.19
Saint Louis	4.22	5.10	5.52	6.27	5.29	5.47	4.51	4.03	4.54	4.19	4.18	4.21
Denver	3.57	4.53	4.42	3.22	4.29	3.09	4.13	3.53	3.48	3.35	3.52	4.00
Greenwich	4.16	5.44	7.16	7.40	3.04	3.44	3.16	2.56	2.20	3.00	4.24	4.08

A difficulty is experienced here in determining whether the epoch in passing from month to month has gone forward or backward. This can only be met by calculation for shorter periods of time. The uncertainty is very considerable. For example, in case of several of the stations it is impossible to decide at what point in the fall the epoch returns to the first quadrant, or whether it returns at all.

DISTRIBUTION OF BAROMETRIC PRESSURE AT NEW YORK, N. Y.

Table XIV shows the distribution of the barometric pressure for every .05 inch for every month from April, 1888, to December, 1891, at New York, together with the *à priori* distribution as deduced from the probability curve $y = \frac{h}{\sqrt{\pi}} e^{-h^2x^2}$.

TABLE XIV.—*Frequency of barometric heights at New York, N. Y., from hourly barograph readings.*

Base number, 28+ inches. JANUARY. Mean 29.884. Above 539. Below 461. $h = .229$.

	.70	.75	.80	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
1889	.....	.....	.....	.....	.....	8	6	4	8	24	6	5	11	27	18	21	18	24	25	23	57	28
1890	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4	6	4	9	14	21	28	47	33	41
1891	3	3	1	1	2	2	3	2	4	13	9	11	7	9	7	13	14	19	34	31	34	42
Sum	3	3	1	1	2	10	9	6	12	37	15	16	22	42	29	43	46	64	87	101	124	111
Per mille	1	1	0	0	1	4	4	3	5	17	7	7	10	19	13	19	21	29	39	45	56	50
Probable	.....	.....	.....	1	0	1	2	1	4	5	6	10	12	17	21	28	32	40	45	51	57	60
Difference	1	1	0	— 1	1	3	2	2	1	12	1	— 3	— 2	2	— 8	— 9	—11	—11	— 6	— 6	— 1	—10

	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
1889	36	21	45	95	31	19	37	38	38	17	18	23	13	.....	.....	.....	.....	.....	.....	.....	.....	.....
1890	56	38	35	33	45	31	32	46	43	24	38	30	36	38	2	6	4	.....	.....	.....	.....	.....
1891	52	90	102	40	62	32	13	23	35	18	13	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sum	144	149	182	168	138	82	82	107	116	59	69	53	49	38	2	6	4	.....	.....	.....	.....	.....
Per mille	65	67	82	75	62	37	37	48	52	26	31	24	22	17	1	3	2	.....	.....	.....	.....	.....
Probable	63	65	63	62	58	54	47	42	34	29	24	18	15	10	7	6	4	2	2	0	1	1
Difference	2	2	19	13	4	—17	—10	6	18	— 3	7	6	7	7	— 6	— 3	— 2	— 2	— 2	0	— 1	— 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

FEBRUARY. Mean 29.903. Above 495. Below 505. h=.214.

	.80	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85
1889	.....	.....	.....	.....	.....	.....	.....	.....	9	13	7	5	4	13	28	63	49	33	28	42	25	34
1890	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	14	12	6	11	17	23	32	25	29	32	42	67
1891	.....	.....	.....	.....	.....	.....	.....	.....	5	17	17	14	18	28	32	34	25	26	23	22	46	35
Sum	.....	.....	.....	.....	.....	.....	.....	.....	14	32	38	31	28	52	77	120	106	84	80	96	113	136
Per mille	.....	.....	.....	.....	.....	.....	.....	.....	7	16	19	15	14	26	38	60	53	42	40	48	56	67
Probable	1	0	1	1	2	2	5	5	7	10	14	17	21	26	31	37	43	47	53	56	58	60
Difference	− 1	0	− 1	− 1	− 2	− 2	− 5	− 5	0	6	5	− 2	− 7	0	7	23	10	− 5	−13	− 8	− 2	7

	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85	2.90	2.95
1889	32	26	23	12	20	21	9	15	29	23	30	22	21	23	9	4	.....	.....	.....	.....	.....	.....
1890	83	61	44	28	19	20	16	15	26	39	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1891	27	37	30	28	39	41	27	27	37	11	10	12	4	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sum	142	124	97	68	78	82	52	57	92	73	49	34	25	23	9	4	.....	.....	.....	.....	.....	.....
Per mille	70	62	48	34	39	41	26	28	46	36	24	17	12	11	4	2	.....	.....	.....	.....	.....	.....
Probable	60	58	56	53	48	43	38	31	27	22	18	13	11	7	6	4	3	1	2	1	0	1
Difference	10	4	− 8	−19	− 9	− 2	−12	− 3	19	14	6	4	1	4	− 2	− 2	− 3	− 1	− 2	− 1	0	− 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

MARCH. Mean 29.803. Above 536. Below 464. h=.251.

	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
1889	......	......	4	26	4	8	7	15	13	11	4	33	21	35	59	47	75	55	47
1890	......	......	......	......	......	1	3	5	5	9	21	28	40	39	33	32	34	39	58
1891	......	......	......	......	......	......	......	......	5	4	11	17	17	19	16	23	30	35	40
Sum	......	......	4	26	4	9	10	20	23	24	36	78	78	93	108	102	139	129	145
Per mille	......	......	2	12	2	4	4	9	10	11	16	35	35	42	48	45	62	58	65
Probable	1	0	1	2	2	4	6	9	12	17	23	29	35	44	51	58	64	68	70
Difference	— 1	0	1	10	0	0	— 2	0	— 2	— 6	— 7	6	0	— 2	— 3	—13	— 2	—10	— 5

	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70
1889	56	62	35	32	18	15	23	15	12	1	10	1	......	......	......	......	......	......	......
1890	51	32	50	60	31	33	45	21	16	26	27	5	......	......	......	......	......	......	......
1891	49	65	97	74	55	36	43	37	33	16	9	13	......	......	......	......	......	......	......
Sum	156	159	182	166	104	84	111	73	61	43	46	19	......	......	......	......	......	......	......
Per mille	70	71	82	74	47	38	50	33	28	19	21	8	......	......	......	......	......	......	......
Probable	70	68	64	55	51	44	37	30	24	17	12	10	6	4	3	2	1	0	1
Difference	0	3	18	19	— 4	— 6	13	3	4	2	9	— 2	— 6	— 4	— 3	— 2	— 1	0	— 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

APRIL. Mean 29.844. Above 507. Below 493. *h*=.274.

	·95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80
1888	......	......	......	......	......	......	......	4	5	2	3	6	16	22	54	91	82	44
1889	......	4	9	6	5	9	5	12	29	21	10	28	31	58	33	40	55	67
1890	......	......	......	......	......	......	2	7	13	17	17	8	8	41	32	39	58	33
1891	......	......	......	......	10	5	4	11	31	36	18	8	8	32	61	70	80	49
Sum	......	4	9	6	15	14	11	34	78	76	48	50	63	153	180	240	275	193
Per mille	......	1	3	2	5	5	4	12	27	26	17	17	22	53	62	83	95	67
Probable	1	0	1	2	2	5	7	10	15	21	28	35	45	55	62	69	74	77
Difference	— 1	1	2	0	3	0	— 3	2	12	5	—11	—18	—23	— 2	0	14	21	—10

	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65
1888	41	56	44	30	41	24	34	54	31	29	7.	......	......	......	......	......	......
1889	74	39	29	34	24	37	47	6	8	......	......	......	......	......	......	......	......
1890	44	75	52	49	42	42	67	41	15	6	7	5	......	......	......	......	......
1891	54	67	38	39	23	14	10	16	12	15	9	......	......	......	......	......	......
Sum	213	237	163	152	130	117	158	117	66	50	23	5	......	......	......	......	......
Per mille	74	82	57	53	45	41	55	41	23	17	8	2	......	......	......	......	......
Probable	76	74	67	61	52	42	34	27	19	14	9	6	5	2	1	1	1
Difference	— 2	8	—10	— 8	— 7	— 1	21	14	4	3	— 1	— 4	— 5	— 2	— 1	— 1	— 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

MAY. Mean 29.796. Above 489. Below 511. $h = .437$.

	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30
1888	......	......	......	......	......	8	40	33	83	142	102	51	43	46	62	50	58	26	......	......	......	......
1889	......	......	......	6	28	21	56	74	63	96	76	111	82	35	17	23	12	38	6	......	......	......
1890	......	......	3	34	16	20	34	46	76	78	82	83	81	39	68	49	20	15	......	......	......	......
1891	......	......	......	......	5	8	26	27	41	99	137	97	108	57	56	27	13	4	10	20	9	......
Sum	......	......	3	40	49	57	156	180	263	415	397	342	314	177	203	149	103	83	16	20	9	......
Per mille	......	......	1	13	16	19	52	60	88	139	133	115	106	59	68	50	35	28	5	7	3	......
Probable	1	2	4	7	18	31	49	70	93	111	122	120	109	90	68	44	29	15	9	4	1	1
Difference	− 1	− 2	− 3	6	− 2	−12	3	−10	− 5	28	11	− 5	− 3	−31	0	6	6	13	− 4	3	2	− 1

JUNE. Mean 29.770. Above 506. Below 494. $h = .438$.

	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30
1–18, 1886	......	......	......	......	......	4	25	13	35	55	58	48	26	29	51	57	22	9	......	......	......	......	......
1889	......	......	......	5	25	13	11	13	16	32	49	46	67	55	37	47	16	......	......	......	......	......	......
1890	......	......	......	......	......	......	......	3	25	74	43	47	54	35	34	31	31	28	20	7	......	......	......
1891	......	......	......	......	......	......	9	27	22	25	49	45	48	37	53	95	22	......	......	......	......	......	......
A. Sum	......	......	......	5	25	17	45	56	98	186	199	186	195	156	175	230	91	37	20	7	......	......	......
19–30, 1888	......	......	......	......	......	......	23	43	31	39	27	24	16	7	5	16	38	19	......	......	......	......	......
1890	......	......	......	......	......	......	......	12	62	46	57	29	16	37	15	14	......	......	......	......	......	......	......
1891	......	......	......	......	......	6	20	46	59	48	75	28	6	......	......	......	......	......	......	......	......	......	......
B. Sum	......	......	......	......	......	6	43	101	152	133	159	81	38	44	20	30	38	19	......	......	......	......	......
¾ A + ⅔ B	......	......	......	4	19	17	63	109	175	228	255	193	172	146	145	192	94	41	15	5	......	......	......
Per mille	......	......	......	2	10	9	34	58	93	122	136	103	92	78	77	102	50	22	8	3	......	......	......
Probable	1	1	3	6	13	24	39	60	82	104	118	122	116	100	78	55	36	21	12	5	3	0	1
Difference	− 1	− 1	− 3	− 4	− 3	−15	− 5	− 2	11	18	18	−19	−24	−22	− 1	47	14	1	− 4	− 2	− 3	0	− 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

JULY. Mean 29.875. Above 566. Below 434. $h = .429$.

	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40
1888				4	11	18	6	8	16	30	63	77	83	98	85	149	58	19	14	5			
1890						22	30	28	28	53	85	78	126	113	65	57	42	17					
1891					6	29	45	63	80	143	77	90	45	55	18	38	45	10					
Sum				4	17	69	81	99	124	226	225	245	254	266	168	244	145	46	14	5			
Per mille				2	8	31	36	44	56	101	101	110	113	119	75	109	65	21	6	2			
Probable	1	1	3	7	13	23	40	57	80	101	114	120	114	101	80	57	40	23	13	7	3	1	1
Difference	−1	−1	−3	−5	−5	8	−4	−13	−24	0	−13	−10	−1	18	−5	52	25	−2	−7	−5	−3	−1	−1

AUGUST. Mean 29.874. Above 559. Below 441. $h = .466$.

	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35
1–7, 1888								7	24	44	36	23	29	5							
1890									8	2	10	28	57	53	10						
1891				10	18	5	7	12	8	26	21	33	28								
A. Sum				10	18	5	7	19	40	72	67	84	114	58	10						
8–31, 1888			5	4	1	2	2	3	3	5	45	73	95	71	121	70	36	27	13		
1889				7	12	15	13	46	61	75	44	98	107	43	31	21	3				
1890			6	4	6	29	32	55	57	89	72	83	72	43	19	9					
1891				12	8	13	56	61	138	100	68	59	35	24	2						
B. Sum			11	27	27	59	103	165	259	269	229	313	309	181	173	100	39	27	13		
$\frac{1}{12}$ A + $\frac{6}{31}$ B			2	6	7	12	20	33	53	54	49	67	68	39	34	19	7	5	2		
Per mille			4	13	15	25	42	69	111	113	103	140	143	82	71	40	15	10	4		
Probable	1	1	5	10	20	34	55	81	107	123	131	123	106	79	55	35	18	10	4	1	1
Difference	−1	−1	−1	3	−5	−9	−13	−12	4	−10	−28	17	37	3	16	5	−3	0	0	−1	−1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

SEPTEMBER. Mean 29.912. Above 555. Below 445. *h*=.447.

	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85
1888	.....	.....	5	10	3	6	7	14	5	44	43	93	77
1889	11	7	9	6	14	17	9	6	35	79	32	45	96
1890	.....	.....	.....	.....	.....	.....	.....	12	19	41	40	77	72
1891	.....	.....	.....	.....	.....	.....	3	5	14	24	25	56	108
Sum	11	7	14	16	17	23	19	37	73	188	140	271	353
Per mille	4	3	5	6	6	8	7	13	25	65	49	94	122
Probable	.....	.....	1	1	3	6	14	24	42	62	87	108	122
Difference	4	3	4	5	3	2	− 7	−11	−17	3	−38	−14	0

	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55
1888	100	84	76	46	19	24	9	5	6	3	11	14	11	5
1889	121	139	38	25	31	.....	.....	.....	.....	.....	.....	.....	.....	.....
1890	97	92	120	62	71	17	.....	.....	.....	.....	.....	.....	.....	.....
1891	154	99	72	72	39	42	7	.....	.....	.....	.....	.....	.....	.....
Sum	472	414	306	205	160	83	16	5	6	3	11	14	11	5
Per mille	164	144	106	71	56	29	6	2	2	1	4	5	4	2
Probable	123	117	98	74	51	32	19	9	4	2	1	.....	.....	.....
Difference	41	27	8	− 3	5	− 3	−13	− 7	− 2	− 1	3	5	4	2

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

OCTOBER. Mean 29.789. Above 558. Below 442. $h = .306$.

	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70
1888	......	......	......	......	3	10	16	33	18	11	47	55	36	43	72
1889	......	......	......	......	......	......	......	10	13	12	13	10	21	39	80
1890	......	......	6	5	4	35	17	39	26	29	48	46	53	44	63
1891	......	......	......	......	......	......	......	......	......	19	37	57	46	44	48
Sum	......	......	6	5	7	45	33	82	57	71	145	168	156	170	263
Per mille	......	......	2	2	2	15	11	28	19	24	49	56	52	57	88
Probable	1	0	2	2	5	7	12	18	25	34	45	56	68	76	83
Difference	−1	0	0	0	−3	8	−1	10	−6	−10	4	0	−16	−19	5

	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50
1888	59	80	53	34	43	23	23	45	20	20	......	......	......	......	......	......
1889	76	117	110	77	76	21	12	19	25	13	......	......	......	......	......	......
1890	79	50	36	21	23	21	48	36	15	......	......	......	......	......	......	......
1891	66	64	51	61	32	38	24	42	18	52	24	16	2	......	......	......
Sum	280	311	253	193	174	103	107	142	78	85	24	16	2	......	......	......
Per mille	94	105	85	65	58	35	36	47	26	29	8	5	1	......	......	......
Probable	85	85	80	73	62	52	39	31	21	15	9	7	3	2	1	1
Difference	9	20	5	−8	−4	−17	−3	16	5	14	−1	−2	−2	−2	−1	−1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

NOVEMBER. Mean 29.902. Above 541. Below 459. *h*=.242.

	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85
1888	......	......	7	13	3	4	2	9	7	5	13	11	33	37	38	33	30	21	17	29
1889	......	......	......	......	......	11	10	12	10	4	6	17	33	38	25	41	31	24	22	29
1890	......	......	......	......	......	......	......	3	2	4	14	3	16	42	48	36	42	39	49	65
1891	......	......	......	3	2	2	2	4	4	7	6	14	14	20	19	20	21	43	73	69
Sum	......	......	7	16	5	17	14	28	23	20	39	45	96	137	130	130	124	127	161	192
Per mille	......	......	2	6	2	6	5	10	8	7	14	16	33	48	45	45	43	44	56	67
Probable	1	0	1	0	3	3	5	7	10	13	18	24	30	36	43	51	57	62	66	67
Difference	− 1	0	1	6	− 1	3	0	3	− 2	− 6	− 4	− 8	3	12	2	− 6	−14	−18	−10	0

	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
1888	25	33	31	42	63	28	33	28	53	26	15	17	7	6	1	......	......	......	......	......
1889	60	92	97	46	15	8	16	10	9	19	27	8	......	......	......	......	......	......	......	......
1890	104	53	70	52	56	22	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1891	38	39	40	47	54	39	24	16	15	26	19	14	16	6	4	......	......	......	......	......
Sum	227	217	238	187	188	97	73	54	77	71	61	39	23	12	5	......	......	......	......	......
Per mille	79	75	83	65	65	34	25	19	27	25	21	14	8	4	2	......	......	......	......	......
Probable	68	66	62	57	52	44	36	30	25	19	13	10	7	6	3	2	1	1	0	1
Difference	11	9	21	8	13	−10	−11	−11	2	6	8	4	1	− 2	− 1	− 2	− 1	− 1	0	− 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

DECEMBER. Mean 29.896. Above 551. Below 449. $h=.256$.

	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60
1888	1	3	1	2	......	1	2	1	2	2	1	2	2	2	2	4	14	15	15	19	16	33	35
1889	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	12	23	48	19	21	30	18	18
1890	......	......	......	......	......	......	......	......	......	......	......	......	3	2	1	2	4	4	3	5	4	1	18
1891	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1	6	2	5	16	22	10	18	12
Sum	1	3	1	2	......	1	2	1	2	2	1	2	5	4	4	24	43	72	53	67	60	70	83
Per mille	0	1	0	1	......	0	1	0	1	1	0	1	2	1	1	8	14	24	18	23	20	24	28
Probable	......	......	......	......	......	......	......	......	......	1	0	1	2	2	4	6	8	13	17	22	30	36	45
Difference	0	1	0	1	......	0	1	0	1	0	0	0	0	−1	−3	2	6	11	1	1	−10	−12	−17

	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80
1888	42	50	39	55	80	48	33	38	30	33	24	22	30	17	24	4	......	......	......	......	......	......	......	......
1889	30	41	36	35	40	48	46	44	69	48	40	23	20	18	15	2	......	......	......	......	......	......	......	......
1890	27	54	52	77	45	66	55	59	96	40	23	28	32	14	3	3	4	2	1	10	6	......	......	......
1891	14	21	39	31	37	67	62	67	81	59	72	56	9	11	26	......	......	......	......	......	......	......	......	......
Sum	113	166	166	198	202	229	196	208	276	180	159	129	91	60	68	9	4	2	1	10	6	......	......	......
Per mille	38	56	56	67	68	77	66	70	93	60	53	43	31	20	23	3	1	1	0	3	2	......	......	......
Probable	52	60	66	69	72	71	69	65	58	51	44	35	25	22	17	11	8	6	4	1	2	1	0	1
Difference	−14	−4	−10	−2	−4	6	−3	5	35	9	9	8	3	−2	6	−8	−7	−5	−4	2	0	−1	0	−1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

YEAR (in per milles). Mean 29.854. Above 527. Below 473. $h = .297$.

	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55
January	......	......	......	......	1	1	0	0	1	4	4	3	5	17	7	7	10	19	13	19	21	29
February	......	......	......	......	......	......	......	......	......	......	......	......	......	......	7	16	19	15	14	26	38	60
March	......	......	......	......	......	......	......	......	......	2	12	2	4	4	9	10	11	16	35	35	42	48
April	......	......	......	......	......	......	......	......	......	......	1	3	2	5	5	4	12	27	26	17	17	22
May	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1	13	16	19	52
June	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2	10	9	34	58
July	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2	8	31
August	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4	13	15
September	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4	3	5	6	6	8	7
October	......	......	......	......	......	......	......	......	......	......	......	......	2	2	2	15	11	28	19	24	49	56
November	......	......	......	......	......	......	......	......	......	......	2	6	2	6	5	10	8	7	14	16	33	48
December	0	1	0	1	......	0	1	0	1	1	0	1	2	1	1	8	14	24	18	23	20	24
Sums	0	1	0	1	1	1	1	0	2	7	19	15	17	35	36	74	88	144	168	197	302	450
Means	......	......	......	......	......	......	......	......	......	1	2	1	1	3	3	6	7	12	14	16	25	37
Probable	......	......	......	......	......	......	......	......	......	......	......	1	1	1	2	5	7	12	16	25	31	43
Difference	......	......	......	......	......	......	......	......	......	1	2	0	0	2	1	1	0	0	− 2	− 9	− 6	− 6

	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65
January	39	45	56	50	65	67	82	75	62	37	37	48	52	26	31	24	22	17	1	3	2	......
February	53	42	40	48	56	67	70	62	48	34	39	41	26	28	46	36	24	17	12	11	4	2
March	45	62	58	65	70	71	82	74	47	38	50	33	28	19	21	8	......	......	......	......	......	......
April	53	62	83	95	67	74	82	57	53	45	41	55	41	23	17	8	2	......	......	......	......	......
May	60	88	139	133	115	106	59	68	50	35	28	5	7	3	......	......	......	......	......	......	......	......
June	93	122	136	103	92	78	77	102	50	22	8	3	......	......	......	......	......	......	......	......	......	......
July	36	44	56	101	101	110	113	119	75	109	65	21	6	2	......	......	......	......	......	......	......	......
August	25	42	69	111	113	103	140	143	82	71	40	15	10	4	......	......	......	......	......	......	......	......
September	13	25	65	49	94	122	164	144	106	71	56	29	6	2	2	1	4	5	4	2	......	......
October	52	57	88	94	105	85	65	58	35	36	47	26	29	8	5	1	......	......	......	......	......	......
November	45	45	43	44	56	67	79	75	83	65	65	34	25	19	27	25	21	14	8	4	2	......
December	28	38	56	56	67	68	77	66	70	93	60	53	43	31	20	23	3	1	1	0	3	2
Sums	542	672	889	949	1,001	1,018	1,090	1,043	761	656	536	363	273	165	169	126	76	54	26	20	11	4
Means	45	56	74	79	83	85	91	87	62	55	45	30	23	14	14	10	6	4	2	2	1	......
Probable	52	64	72	79	82	83	80	74	64	55	43	34	25	18	12	8	5	2	2	1	1	......
Difference	−7	− 8	2	0	1	2	11	13	− 2	0	2	− 4	− 2	− 4	2	2	1	2	0	1	0	......

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 7.

REPORT

OF THE

FIRST ANNUAL MEETING

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U. S. DEPARTMENT OF AGRICULTURE.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., December 22, 1892.

SIR: I have the honor to transmit herewith a report of the first annual meeting of the American Association of State Weather Services co-operating with the Weather Bureau, U. S. Department of Agriculture, which was held at Rochester, New York, August 15 and 16, 1892.

As the chief object of the organization of the State Weather Services has been to increase the usefulness of the work of the Weather Bureau, and as there is so much in the report bearing directly upon the distribution of weather forecasts for the benefit of the people, I recommend that this report be published as a bulletin of this Bureau.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. J. M. RUSK,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

American Association of
State Weather Services,
Washington, D. C., December 20, 1892.

Sir: I have the honor to submit herewith a report of the meeting of the American Association of State Weather Services co-operating with the Weather Bureau, U. S. Department of Agriculture, which was held at Rochester, New York, August 15 and 16, 1892. The report has been prepared in accordance with your suggestions, with a view to its publication as a bulletin of the Weather Bureau.

Very respectfully,

H. H. C. Dunwoody,
President.

Mark W. Harrington,
Chief of Weather Bureau.

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TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

NOVEMBER. Mean 29.902. Above 541. Below 459. *h*=.242.

	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85
1888	......	......	7	13	3	4	2	9	7	5	13	11	33	37	38	33	30	21	17	29
1889	......	......	......	......	......	11	10	12	10	4	6	17	33	38	25	41	31	24	22	29
1890	......	......	......	......	......	......	......	3	2	4	14	3	16	42	48	36	42	39	49	65
1891	......	......	......	3	2	2	2	4	4	7	6	14	14	20	19	20	21	43	73	.69
Sum	......	......	7	16	5	17	14	28	23	20	39	45	96	137	130	130	124	127	161	192
Per mille	......	......	2	6	2	6	5	10	8	7	14	16	33	48	45	45	43	44	56	67
Probable	1	0	1	0	3	3	5	7	10	13	18	24	30	36	43	51	57	62	66	67
Difference	— 1	0	1	6	— 1	3	0	3	— 2	— 6	— 4	— 8	3	12	2	— 6	—14	—18	—10	0

	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
1888	25	33	31	42	63	28	33	28	53	26	15	17	7	6	1	......	......	......	......	......
1889	60	92	97	46	15	8	16	10	9	19	27	8	......	......	......	......	......	......	......	......
1890	104	53	70	52	56	22	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1891	38	39	40	47	54	39	24	16	15	26	19	14	16	6	4	......	......	......	......	......
Sum	227	217	238	187	188	97	73	54	77	71	61	39	23	12	5	......	......	......	......	......
Per mille	79	75	83	65	65	34	25	19	27	25	21	14	8	4	2	......	......	......	......	......
Probable	68	66	62	57	52	44	36	30	25	19	13	10	7	6	3	2	1	1	0	1
Difference	11	9	21	8	13	—10	—11	—11	2	6	8	4	1	— 2	— 1	— 2	— 1	— 1	0	— 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

DECEMBER. Mean 29.896. Above 551. Below 449. *h*=.256.

	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60
1888	1	3	1	2	......	1	2	1	2	2	1	2	2	2	2	4	14	15	15	19	16	33	35
1889	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	12	23	48	19	21	30	18	18
1890	......	......	......	......	......	......	......	......	......	......	......	......	3	2	1	2	4	4	3	5	4	1	18
1891	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1	6	2	5	16	22	10	18	12
Sum	1	3	1	2	......	1	2	1	2	2	1	2	5	4	4	24	43	72	53	67	60	70	83
Per mille	0	1	0	1	......	0	1	0	1	1	0	1	2	1	1	8	14	24	18	23	20	24	28
Probable	......	......	......	......	......	......	......	......	......	1	0	1	2	2	4	6	8	13	17	22	30	36	45
Difference	0	1	0	1	......	0	1	0	1	0	0	0	0	— 1	— 3	2	6	11	1	1	—10	—12	—17

	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80
1888	42	50	39	55	80	48	33	38	30	33	24	22	30	17	24	4	......	......	......	......	......	......	......	......
1889	30	41	36	35	40	48	46	44	69	48	40	23	20	18	15	2	......	......	......	......	......	......	......	......
1890	27	54	52	77	45	66	55	59	96	40	23	28	32	14	3	3	4	2	1	10	6	......	......	......
1891	14	21	39	31	37	67	62	67	81	59	72	56	9	11	26	......	......	......	......	......	......	......	......	......
Sum	113	166	166	198	202	229	196	208	276	180	159	129	91	60	68	9	4	2	1	10	6	......	......	......
Per mille	38	56	56	67	68	77	66	70	93	60	53	43	31	20	23	3	1	1	0	3	2	......	......	......
Probable	52	60	66	69	72	71	69	65	58	51	44	35	25	22	17	11	8	6	4	1	2	1	0	1
Difference	—14	— 4	—10	— 2	— 4	6	— 3	5	35	9	9	8	3	— 2	6	— 8	— 7	— 5	— 4	2	0	— 1	0	— 1

TABLE XIV.—*Frequency of barometric heights, &c.*—Continued.

YEAR (in per milles). Mean 29.854. Above 527. Below 473. $h = .297$.

	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55
January	......	......	......	......	1	1	0	0	1	4	4	3	5	17	7	7	10	19	13	19	21	29
February	......	......	......	......	......	......	......	......	......	......	......	......	......	......	7	16	19	15	14	26	38	60
March	......	......	......	......	......	......	......	......	......	2	12	2	4	4	9	10	11	16	35	35	42	48
April	......	......	......	......	......	......	......	......	......	......	1	3	2	5	5	4	12	27	26	17	17	22
May	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1	13	16	19	52
June	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2	10	9	34	58
July	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2	8	31
August	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4	13	15
September	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4	3	5	6	6	8	7
October	......	......	......	......	......	......	......	......	......	......	......	......	2	2	2	15	11	28	19	24	49	56
November	......	......	......	......	......	......	......	......	......	......	2	6	2	6	5	10	8	7	14	16	33	48
December	0	1	0	1	......	0	1	0	1	1	0	1	2	1	1	8	14	24	18	23	20	24
Sums	0	1	0	1	1	1	1	0	2	7	19	15	17	35	36	74	88	144	168	197	302	450
Means	......	......	......	......	......	......	......	......	......	1	2	1	1	3	3	6	7	12	14	16	25	37
Probable	......	......	......	......	......	......	......	......	......	......	......	1	1	1	2	5	7	12	16	25	31	43
Difference	......	......	......	......	......	......	......	......	......	1	2	0	0	2	1	1	0	0	− 2	− 9	− 6	− 6

	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	2.55	2.60	2.65
January	39	45	56	50	65	67	82	75	62	37	37	48	52	26	31	24	22	17	1	3	2	......
February	53	42	40	48	56	67	70	62	48	34	39	41	26	28	46	36	24	17	12	11	4	2
March	45	62	58	65	70	71	82	74	47	38	50	33	28	19	21	8	......	......	......	......	......	......
April	53	62	83	95	67	74	82	57	53	45	41	55	41	23	17	8	2	......	......	......	......	......
May	60	88	139	133	115	106	59	68	50	35	28	5	7	3	......	......	......	......	......	......	......	......
June	93	122	136	103	92	78	77	102	50	22	8	3	......	......	......	......	......	......	......	......	......	......
July	36	44	56	101	101	110	113	119	75	109	65	21	6	2	......	......	......	......	......	......	......	......
August	25	42	69	111	113	103	140	143	82	71	40	15	10	4	......	......	......	......	......	......	......	......
September	13	25	65	49	94	122	164	144	106	71	56	29	6	2	2	1	4	5	4	2	......	......
October	52	57	88	94	105	85	65	58	35	36	47	26	29	8	5	1	......	......	......	......	......	......
November	45	45	43	44	56	67	79	75	83	65	65	34	25	19	27	25	21	14	8	4	2	......
December	28	38	50	56	67	68	77	66	70	93	60	53	43	31	20	23	3	1	1	0	3	2
Sums	542	672	889	949	1,001	1,018	1,090	1,043	761	656	536	363	273	165	169	126	76	54	26	20	11	4
Means	45	56	74	79	83	85	91	87	62	55	45	30	23	14	14	10	6	4	2	2	1	......
Probable	52	64	72	79	82	83	80	74	64	55	43	34	25	18	12	8	5	2	2	1	1	......
Difference	−7	− 8	2	0	1	2	11	13	− 2	0	2	− 4	− 2	− 4	2	2	1	2	0	1	0	......

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 7.

REPORT

OF THE

FIRST ANNUAL MEETING

OF THE

AMERICAN ASSOCIATION OF STATE WEATHER SERVICES,

CO-OPERATING WITH THE WEATHER BUREAU,
U. S. DEPARTMENT OF AGRICULTURE.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., December 22, 1892.

Sir: I have the honor to transmit herewith a report of the first annual meeting of the American Association of State Weather Services co-operating with the Weather Bureau, U. S. Department of Agriculture, which was held at Rochester, New York, August 15 and 16, 1892.

As the chief object of the organization of the State Weather Services has been to increase the usefulness of the work of the Weather Bureau, and as there is so much in the report bearing directly upon the distribution of weather forecasts for the benefit of the people, I recommend that this report be published as a bulletin of this Bureau.

Very respectfully,

Mark W. Harrington,
Chief of Weather Bureau.

Hon. J. M. Rusk,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

American Association of
State Weather Services,
Washington, D. C., December 20, 1892.

Sir: I have the honor to submit herewith a report of the meeting of the American Association of State Weather Services co-operating with the Weather Bureau, U. S. Department of Agriculture, which was held at Rochester, New York, August 15 and 16, 1892. The report has been prepared in accordance with your suggestions, with a view to its publication as a bulletin of the Weather Bureau.

Very respectfully,

H. H. C. Dunwoody,
President.

Mark W. Harrington,
Chief of Weather Bureau.

being dependent upon well-defined positions, and not upon colors, they may be read in all weather and at comparatively long distances.

It was claimed for this system that it is simple, durable, and costs only about $10, which is about the cost of a good set of flags. It was thought that there was nothing about it to get out of order, and the apparatus would last about six years. It was stated that in a test which had been made of the apparatus it was found that the vane would not conform to the direction of the wind in the manner of a wind-vane, but that that feature could doubtless be remedied.

Signals made of tin were suggested, and it was reported that such signals had been used in Ohio for over a year and are now in as good condition as when they were put up.

The throwing up of colored lights by means of bombs was also referred to, but it was stated that they had been formerly tried and had not proved a success.

Reference was also made to the search light as a means of disseminating forecasts by throwing a flash or beam of light on a cloud in the sky, and in fact experiments had shown that such a flash would be visible with a perfectly clear sky. This means of displaying weather forecasts was regarded as very interesting and likely to prove valuable, and it was stated that it is proposed by the director of the experiment station in Massachusetts to construct an electric search light by means of which forecasts will be signaled.

In consideration of the importance of the subject it was referred to a committee, consisting of Messrs. Conger, Glenn, and Kerkam, with instructions to consider and recommend the best means of signaling weather forecasts by displaymen, and to submit their report to the president of the association. (For report of committee see Appendix B.)

EIGHTH SUBJECT.

Inspection of stations of voluntary observers.

The proposition to inspect voluntary stations was most heartily indorsed by all the gentlemen who participated in the discussion of the subject, and the opinion was freely expressed that periodical inspections of such stations by a representative of each State weather service would go far towards improving the value of the observations furnished by voluntary observers, and to greatly enhance the popularity of State weather service work. The association was told of the great good that had resulted from the inspections in a few States where they have been made to a greater or less extent, how the flagging interest of many voluntary observers had been revived upon meeting the director or assistant director and receiving from him information as to the value of the observations, the great and increasing usefulness of State weather service work generally, and being carefully instructed as to the details of his work, the proper manner of setting up and exposing the instruments, etc. It was believed that the interest of the community in State weather service work could be aroused by meeting and conversing with the prominent citizens and editors of newspapers at the stations, and by visiting farmers' institutes and distributing weather charts, bulletins, and reports, and explaining the same. It was also suggested that the information which could be obtained by the inspector relative to the elevation of stations, the topography of the country, the character of the soil, the best means of communication by wire and rail, etc., would be of much value to the State and National services. It was thought that the Weather Bureau might grant its observers, detailed upon State weather service work, thirty days annually for the purpose of inspecting the voluntary stations, together with a pecuniary allowance sufficient to defray the necessary expenses.

A motion was submitted and carried, expressing the opinion of the association that an inspection of the voluntary stations should be made annually under the direction of the Chief of the Weather Bureau, it being the opinion of the association that such inspections would result in great advantage to the State and National services.

At 12 o'clock noon the association adjourned until 3 p. m.

After the noon recess the following subject was presented for discussion:

NINTH SUBJECT.

The relation of State weather services to agricultural colleges and experiment stations.

As an introduction of this subject for discussion Professor Harrington stated that it was one of very great interest to the central office at Washington. It had frequently been suggested that the State weather service centers should be located at the experiment stations or agricultural colleges, it being claimed that such action would result in advantage both to the agricultural interests and to the State weather services. It has also been alleged that as most of our observations are taken on the tops of high buildings they are not suitable for agricultural purposes. On the other hand it is affirmed that the great meteorological map and forecast work could not be carried on at the experiment stations and colleges, as they are generally situated at places remote from the necessary facilities for properly conducting the work which, for a variety of reasons, must be done at the large centers. The question has had to be considered frequently, and more light is desired upon it. He thought there must be advantage in having closer relations between the two branches of work, but he was not quite certain as to what those relations should be, and would be glad to hear suggestions.*

Discussion of the subject developed the fact that the State weather services are cheerfully co-operating with the experiment stations and agricultural colleges in furnishing such meteorological and crop data as is desired, and in recommending the furnishing of instruments for observation at those places wherever the services of an observer can be procured. The data collected by the State services are available for the use of the agricultural institutions, and the directors of the two branches are in some States jointly carrying on investigations involving questions relating to the effect of weather upon crops. It was almost the unanimous opinion, however, that it would be impracticable to locate the central stations of the State weather services at the experiment stations or agricultural colleges, mainly owing to the lack, at nearly all such places, of the telegraph and mail facilities necessary for the collection and dissemination of the information and reports in time to be of practical value to the community.

It was the sense of the association, as expressed in a motion which was passed, that the State weather services should co-operate with the agricultural colleges and experiment stations in the collection of meteorological data and the publication of the same with mutual benefit to both services.

Exhibit at the World's Fair.

This subject was brought before the association in order to ascertain what preparation is being made looking to an exhibit of State weather service work at the Columbian Exposition. Professor Harrington stated that he had been informed that the space in the building to be occupied by the Weather Bureau exhibit will be so limited that it is thought it will not be possible to provide space for special exhibits of the various State weather services, and therefore it might

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*As to the statement that the observations as carried on at our central stations—in the centers of cities and on the tops of high buildings—are unsuitable for the use of agriculturists, a great deal may be said in palliation. Cities, as such, have very little effect on the observations taken within them, an effect so small that even for such a city as London, England, scores of years of observation are necessary to bring it in evidence in the means of the important meteorological elements of temperature and rainfall. The covering of smoke has a well marked effect on the extremes of temperature, but this being once learned the forecast official can predict frosts from the city as well as from the country. The elevation has an effect on temperature and velocity of the wind, but this can be determined and allowed for. Recent studies show that the catch of rainfall is not sensitive to moderate elevations, but is very sensitive to wind-breaks and eddies. A roof exposure for a rain-gauge may, if properly chosen, be better than one on the ground in a court, or among bushes or trees.—M. W. H.

be well for each State service to have a full and complete display in the State building.

While no definite plan was suggested as to what should constitute the exhibits, it was evident from the remarks of the gentlemen that the plan contemplated by those who have already commenced the preparation of the exhibits is to display carefully constructed charts of each of the more important meteorological elements in such manner as to graphically present the climatology of each State; charts showing the location and character of the various State weather service stations, such as voluntary meteorological stations, weather signal display stations, frost and cold-wave warning stations, etc., while the crop bulletin work will be illustrated in an appropriate manner.

No formal resolution was offered expressing the sentiment of the association on the matter, still it was clearly the desire of the members that each State service should arrange for as creditable an exhibit as possible, and that such exhibit be located in the State building.

As no other general subject was suggested for discussion it was decided to proceed to the election of gentlemen proposed for active or honorary membership of the association.

ELECTION OF ACTIVE MEMBERS.

Messrs. E. T. Turner and W. O. Kerr, of the New York Weather Service, and Mr. E. H. Nimmo, of the Michigan Weather Service, were proposed and elected to active membership.

ELECTION OF HONORARY MEMBERS.

A motion was unanimously passed by the association providing for the election of all active voluntary observers of the various State and Territorial weather services as honorary members of the association, and that such members be notified of their election by the director or assistant director of each State weather service.

The following were also proposed and elected as honorary members: Mr. Edwin F. Smith, secretary California State Agricultural Society, Sacramento, Cal.; Mr. Richard V. Gaines, Mossingford, Va.; Prof. R. Ellsworth Call, Des Moines, Iowa; Mr. Charles H. Nauck, Deputy Commissioner Arkansas Bureau of Mines, Manufacture, and Agriculture, Little Rock, Ark.; Prof. W. H. Niles, Institute of Technology, Boston, Mass.; Prof. G. H. Whitcher, member of the Board of Governors, New Hampshire Agricultural Experiment Station, Hanover, N. H.; Mr. H. G. Reynolds, secretary State Board of Agriculture, Agricultural College, Mich.; Mr. H. F. Alciatore, Weather Bureau, Portland, Oregon; Prof. Louis McLouth, president South Dakota Agricultural College, Brookings, S. Dak.; Mr. C. F. Schneider, Weather Bureau, Detroit, Mich.; and Prof. A. L. McRae, Rolla, Mo.

Votes of thanks were extended to the temporary chairman and president of the association for the courteous and able manner in which they had presided over the proceedings of the meeting, to the American Association for the Advancement of Science, and to the officials of the University of Rochester for the courtesies extended to the members of the association during their stay in the city.

There being no further business before the association a motion was made that the association adjourn *sine die.*

The president desired, before putting the motion, to congratulate the members upon the very successful meeting. He believed that each member would return to his post of duty better able to carry on the work of his State service than he was before the meeting. In his opinion the National service would be benefited, and the people of the country receive substantial benefits from this feature of scientific investigation to be carried on in connection with the American Association for the Advancement of Science. He thought that before adjourning the members would be glad to hear from Professor Harrington.

Replying to this call, Professor Harrington stated that the president had said so much and so well that very little remained for him to say. He had been very much gratified with this meeting. It had been an experiment, having been suggested by the Secretary of the Association, and he himself had thought that there ought to be some means of bringing the State weather services closer together, yet it was with some hesitation that he had consented to call such a meeting. He had also some hesitation in calling the meeting in connection with the American Association, as he did not know whether it would be agreeable to the directors, but all doubt on these points had been removed since the meeting of this association. He thought the meeting had been a decided success, and that the benefits of it would be felt, not only by the State services, but by the National service. He believed that all had been interested and instructed by the discussion which had been carried on, and he trusted that the representatives would return to their work with renewed energy and prospects of increased success, and that the State weather services would continue to grow in usefulness.

The association then, at 6 o'clock p. m., adjourned *sine die.*

APPENDIX A.

REPORT OF COMMITTEE ON INSTRUMENT SHELTER.

NOVEMBER 5, 1892.

To Major H. H. C. DUNWOODY,
President American Association of
State Weather Services, Washington, D. C.:

SIR: Your committee appointed to consider the subject of the "most suitable instrument shelter and manner of exposure to be generally adopted by State weather services" have the honor to submit the following report:

We have considered, first, exposure, with a view to securing free open air readings; second, such a shelter as will properly protect from solar and terrestrial radiations, reflected heat, etc., and still not be too expensive for general adoption.

Difficulty is found in reconciling the opinions of different members of the committee into a unanimous recommendation as to any particular pattern of shelter or the elevation at which it shall be exposed. Papers by Mr. J. Warren Smith, Mr. B. S. Pague, and Prof. H. A. Hazen are forwarded with the request that they be published with the report.

The papers of Messrs. Smith and Pague contain plans of shelters which, with the plan proposed further on in this report, are recommended for test by the Weather Bureau at Washington, D. C., one of each to be constructed and comparative readings made at elevations varying from 4 to 10 feet over sod in level, open field. If the shelter proposed by Mr. Smith, or the one by Mr. Pague, shows better results than the one herewith suggested, said shelter to be considered as the standard in place of the one now recommended. It is admitted by all that a standard Weather Bureau shelter, exposed at an elevation of 10 or 15 feet over sod, will give a true temperature reading, air drainage not being considered, but economy in construction and covenience in gratuitous readings of instruments prompt us to seek for the cheapest and simplest construction and lowest elevation consistent with accuracy. If your committee had the funds to construct patterns of the several shelters herein referred to and time and opportunity to carefully test them, they would ask leave to hold this report until after such test could be made. Probably this could be better done at the central office, where some competent official could be designated to give his whole time to the matter for a considerable period.

Nothing can be said in favor of the window or wall shelter, except that it can be cheaply made. Most buildings are protected by trees or other buildings which obstruct the free air circulation; the building itself is always a potent influence in restricting air currents, and in establishing local temperatures that are not common to the surrounding air. Some observers are using the wall or similar shelters, and for want of funds probably no immediate change can be made, but as opportunities offer the standard shelter and exposure might be substituted. The tree exposure should not be thought of, for at one season foliage is dense and at another there is none. Even with a thick covering of leaves there will always be an occasional sun ray to pass entirely through. If the instruments are not protected on all sides by a board shelter, some of these penetrating rays will, at times, impinge upon it and vitiate the readings. Hence, just as complete a shelter will be here needed as in the open field, and the only agency of the tree is to interfere with natural ventilation.

RECOMMENDATION.

If it should not be thought practicable by the Chief of the Bureau to direct the making of the test suggested, then your committee, with their present knowledge of the subject, respectfully recommend the adoption of a modification of the design shown on page 22 of "Instructions for Voluntary Observers;" that the inside back vertical measurements be 26 inches in the clear and the base a rectangle 26 x 18 inches; that it be exposed over sod on ground as nearly level as possible, at an elevation of 4½ feet for the bottom of the shelter, or about 5½ feet for the pins supporting thermometers.

A width and height of 26 inches will allow the maximum thermometer to swing with an inch margin all around. As economy is an important factor, we believe that the depth of 3 feet in the present standard shelter can be reduced to 18 inches without in any way impairing the accuracy of the readings.

This will give room for the maximum and minimum thermometers and for the dry and wet bulb instruments; the dry and wet bulb, of course, to be placed one or two inches back of the plane in which the maximum swings. As few, if any, voluntary observers use the whirling psychrometer, it is not necessary to allow space for that purpose.

The immediate effect of ground radiation at night and reflection by day in air gently in motion, is inappreciable at an elevation of 4 feet. With instruments at a height of 5½ feet placed at least 50 feet from trees or buildings and care exercised to avoid air pockets which may collect the cold air by drainage from higher ground, such readings will be secured as will be of the greatest value to climatological students, to the agricultural interests, and especially will they be such as are needed by local forecast officials in studying local county conditions in their frost-warning work.

Readings can be taken by observers standing on the ground, and the instruments will be in the line of vision of a person of average height.

The shelter can be exposed on a flat roof where an open sod exposure can not be secured, but in that case it will be necessary to lay a platform 20 feet square, and to have shelter at the same elevation above platform as provided for sod exposure. But the sod exposure should be considered as the standard. In fact there are so few voluntary observers using roof exposure that it is hardly worth while to consider it.

An offer is in the hands of your committee from a sash and blind factory of Milwaukee, Wis., to manufacture the shelters at $6 apiece, boxed and delivered on cars. By having several State services, covering contiguous territory, combine in their purchase of shelters, and order from a factory that has been induced to make a low price in consideration of the number sold, a minimum price and uniformity of construction will be secured. It was by representing to the Milwaukee firm that probably Michigan, Iowa, Illinois, Minnesota, and the Dakotas would order from them that this rate was given. They also thought that if orders were numerous enough to justify them in getting out at one time by machinery lumber enough for 25 or 50 shelters the price could be brought down to $4 each.

Very respectfully,

W. L. MOORE.
J. WARREN SMITH.

I concur in this report with the exception as to the elevation of the bottom of the shelter; 4½ feet is entirely too low an elevation for the bottom of the shelter; a man 5 feet 10 inches in height would have to stoop over to read the thermometer. A box or cheap step can easily be secured to raise the observer 3 feet, and then having the bottom of the shelter 7½ feet above the ground would raise the thermometer to about 8 feet 10 inches, which is certainly none too low to escape effect of radiation, etc.; therefore, substituting 7½ feet for 4½ feet elevation of bottom of shelter, I concur in this report.

B. S. PAGUE.

Paper by J. Warren Smith, Director New England Weather Service, Boston, Mass.

Fig. 1 shows a shelter with the instruments in position that, if found accurate after testing, will combine cheapness with simplicity. For ordinary voluntary observer work the shelter should be about 3 feet long and 2 feet wide on the bottom, with the sides 2 feet in width. Both sides and ends should be made with ordinary lattice work. The side posts may be made of 2 x 4 pieces, and should go to

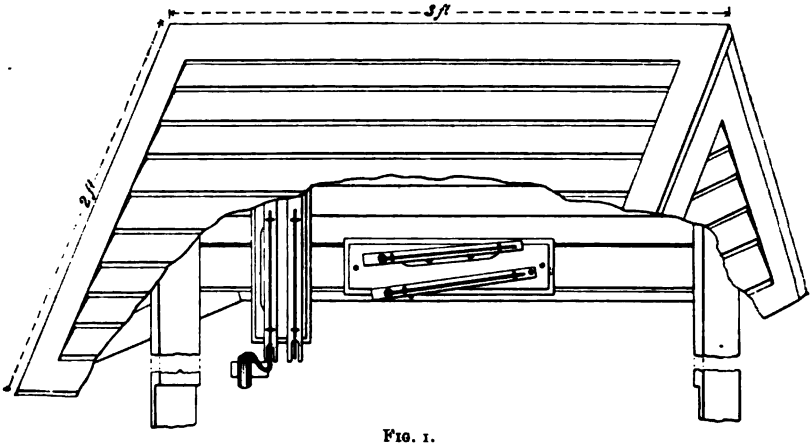

FIG. 1.

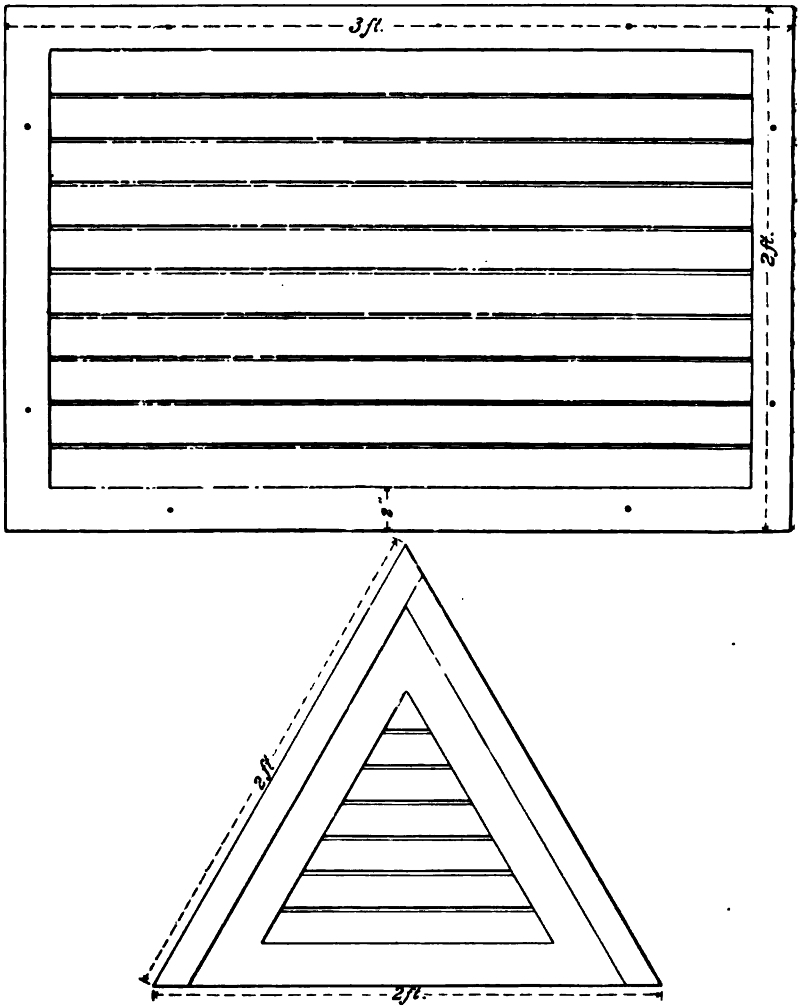

FIG. 2.

the top of the shelter to give it strength. The lower ends of these should be about 18 inches below the shelter and fitted with holes for bolting to posts in the ground, all to be of such height that the eye of the observer will come on a level with the thermometers while standing on the ground, or on one step above the ground. The piece running across to support the thermometers should be attached to the back side of the posts so as to bring the thermometers nearly under the middle of the shelter. If found necessary for protection a wire netting can be placed for the bottom, with a hinged door for letting down, or a wooden lattice-work bottom may be put in.

Fig. 2 shows a front view of one side piece and the end view of the shelter. Unless the Chief of the Bureau can see serious objections to this shelter, I recommend that it be thoroughly tested.

J. Warren Smith.

Paper of Mr. B. S. Pague, Local Forecast Official, Weather Bureau, Assistant Director, Oregon Weather Service.

The proper exposure of thermometers is the most important feature connected with State weather service work. Every voluntary station should be inspected, and all thermometers have the same exposure throughout the United States. As it now is the climatology of the United States is based on Weather Bureau observations, which do not give the true temperature of the country, but rather that of the city. From personal experience I have found the minimum temperature in the city of Portland, Oregon, to be from 2° to 4° higher than the minimum temperature surrounding the city. Hence, we must first select the location for the instruments and then determine the height above the ground. As a rule, voluntary observers do not use roof exposures, hence roof exposures need not be considered.

Sod exposures should be adopted. There should be as free and perfect ventilation as possible. The thermometers must be protected so that they will not become wet.

It sometimes occurs that a sod exposure cannot be had, in which case it would be well to adopt an exposure on the north side of a building. In selecting locations for exposure it should be borne in mind that positions on a knoll, at the foot of a hill, in a valley, etc., prove causes of inaccuracies. The position should be such as to have the air current and not the local influences which are potent factors. The shelter itself is the main subject for consideration in this report. The standard Weather Bureau shelter answers all purposes, but for voluntary observers it is too expensive; hence a suitable one should be devised. The one mentioned at the Rochester meeting as being used by several voluntary observers in Oregon is satisfactory, cheap, and answers all purposes. It consists of four boards, two of them 8 inches wide and 15 inches long, the other two 6 inches wide and 15 inches long. When put together it appears as shown in Fig. 3.

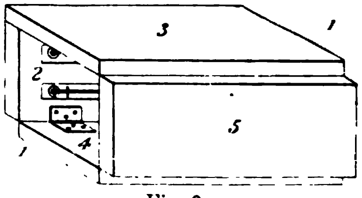

Fig. 3.

The ends, "1," are open, "2, 4, and 5" are perforated with auger holes slanting upwards, and "3," the top, is not perforated, but is a plain board. Open it appears as shown in Fig. 4.

Number "3" (when open) is used as a lid. On the under side (top side when open) a rubber band is stretched across, and that is used to slip the form and pencil underneath, having them both always convenient. Number "2" has thermometers attached.

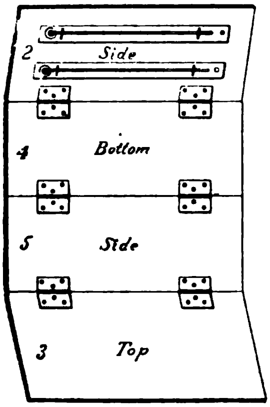

Fig. 4.

This is a small, but convenient and inexpensive shelter. It is suitable to the north side of a building or a tree or other shaded exposure, and is the next best thing to a standard shelter.

For the standard shelter pattern I deem it necessary to have the double roof. The depth of the shelter can be reduced to 18 inches without detriment.· In such a case the door should open on the north side and the thermometer should be placed in the shelter 12 inches from the back; thus allowing farther distance for the thermometers from the continued sunshine on the south side of the shelter. The bottom should be made solid, *i. e.*, not latticed but closely nailed boards. The height of the shelter needs careful study. In Oregon, when possible, the shelter is 12 feet above the sod. This may be rather high, but before the height is reduced below 9 feet most careful experiments should be made. Lower elevation will most certainly allow of inaccurate effect of radiation.

In connection with my idea on this subject, I attach a report prepared, in compliance with a personal request of mine, by Prof. H. A. Hazen, Weather Bureau, by direction of the Chief of the Weather Bureau, to whom the paper of Professor Hazen was submitted before being forwarded to me. Many of the ideas advanced by Professor Hazen coincide with mine, which I have found in actual work. I would recommend that the paper of Professor Hazen be published, or so much of it as meets with the views of the committee.

B. S. PAGUE.

Paper by Prof. H. A. Hazen on exposure of thermometers by voluntary observers.

I shall not consider the very small per cent. of exposures required for the college or amateur observatory. For a roof exposure or one in the open at a height of 10 to 15 feet above sod, the present standard shelter can not be improved upon—it certainly should not be any smaller.

The points to be considered are: First, accuracy; second, convenience; third, expense.

ACCURACY.

I am inclined to think that very erroneous opinions are entertained in England and on the continent as to proper methods of exposure. The Stevenson stand, about 18 by 12 by 18 inches, with double louvers, and exposed 4 feet above sod, would give in our latitudes temperature 4° to 5° too high in bright sunshine. This has been tested. The reason why this has met with so much favor abroad is that that country is 600 to 800 miles farther north than this and does not have the insolation that we have.

An examination of the temperatures observed by voluntary observers will show a serious lack of accordance with those of the regular stations, and it is an interesting fact that with but few exceptions they are higher. This is accounted for from the fact that many of these thermometers are in porches or in summer houses, or in angles where they get little or no air circulation. At Amherst, Mass., there is or was a very elaborate and close low house built at great expense. It looked handsome but was totally unsuited for its purpose. In another case the voluntary observer placed his thermometer in an unused room with windows open. I would like to lay down a few propositions to insure accuracy in a thermometer exposure:

First. There must be as free and perfect a natural ventilation as possible.

Second. An occasional wetting of the thermometer is unobjectionable, and this should not be guarded against to the detriment of (1).

Third. Uniformity—that is, there should be two or three exposures decided upon, and so far as possible insisted on in every case.

Fourth. It should be noted that in most of the cases of inaccuracy it is not due to the immediate environment, but to the position of a house on a knoll, at the foot of a hill, in a valley, etc. An investigation will show that this cause is far more potent than any improper exposure, and it is easy to see that no shelter whatever can ever remedy this evil due to topography.

Fifth. In general, in the shade of a house or among trees no shelter (I mean a box affair) is needed at all. This will not be accepted, probably, but it stands to reason that when a thermometer is in the shade any additional covering will prevent natural ventilation.

Sixth. In the shade of a building or among trees the only sources of error are radiation to a clear sky at night and reflected heat from surrounding objects by day. These two points are continually being insisted upon by theorists, while a few experiments would show them that they are almost inappreciable if the thermometer is on the north wall of the building and there is only greensward in front. In fact, under these circumstances the tendency of a thermometer will be to more than counterbalance terrestrial radiation. The wall of the house will always be cooler than the air by day and warmer than the air at night. These are the principal points, although many other minor ones might be advanced.

My views are, briefly, as follows:

1st. The best exposure for free natural ventilation, least expense, to avoid harmful radiations and reflections, and at the same time to be out of harm's way from cattle, boys, etc., would be on the north side of a tree 1½ feet in diameter and 8 or 9 feet above sod. I would make about three steps—any man could do it without expense—at the foot of the tree, and then put the maximum and minimum thermometers upon a board and screw or nail that to the tree. Of course I do not mean to go into a forest, but I would take an isolated tree either used for shade or in an orchard and convenient to the house. At the top of the board I would put a slanting roof 9 to 10 inches wide to keep off all snow and all rain that does not blow; besides this it would prevent radiation to the sky. I would also put a very light protection on the west side, not more than 6 or 7 inches wide, to prevent the rays of the afternoon sun from striking the bulb. It should be noted that these rays are not so very intense, on account of the low sun, and, in addition, the bulbs being to the left the scale of the thermometer will ward off a part of the heat. If there is no sod underneath, there would be needed a board about a foot wide on the under side to ward off reflected rays. No protection is needed on the east side, for the minimum has been reached before sunrise and the maximum will not be affected till noon or after.

2d. All that has just been said regarding a tree exposure may be applied in so many words to an exposure on the north wall of a building. Here it should be remarked that I have found a continual tendency on the part of amateurs to put thermometers in an angle whenever it could be done. They have thought that the thermometers would be best protected against rain and sometimes wind in an angle. This is true, but the exposure there would be in stagnant air and would be far more objectionable than on a north wall. When there is an L on the north side of a house the exposure should be on the end of that.

3d. Exposure on a wide-extended sod. I do not like this exposure except in a standard shelter, and at least 15 feet above the sod.

Nothing radical should be done without first experimenting upon it. No attention need be paid to the idea that the exposure should be at the average height of a man because we wish to know the temperature where we live or breathe. If the person were going to spend his days and nights right at the thermometer this might be a plausible argument, but as one does not stay there but is continually going from one point out doors where the temperature is high to another 20° or so lower, I do not see the force of this argument. It will be found that all the sources of error are increased the nearer we are to the ground—lack of ventilation, terrestrial radiation, reflection from surroundings, etc.

It would be of great advantage if the Chief of the Bureau or the board on thermometer exposure would initiate a few inexpensive experiments. Place maximum and minimum thermometers upon a board as I have suggested, on the north side of the Weather Bureau office, and 8 or 10 feet above the ground. Also erect upon the greensward, in front, two posts some 10 feet high, and place upon them a board 3 or 4 feet square, and then put on that the additional boards with guards on top, and west, and below. This would be inexpensive, and it might be found more satisfactory than the wall exposure.

One thing should be noted: the temperature found in these locations will not agree exactly with that on the roof. The maximum will be slightly higher and the minimum slightly lower, while the mean of the two will be almost exactly the same in the lower and upper exposures. This will be due not to the error of the exposure but to the fact that the air temperature by day is actually higher in the lower location and by night it is lower.

I will close with a leaf from my experience. My father while preaching at Deerfield, Mass., desired very much to make observations for the New England Meteorological Society. I purchased for him a maximum and minimum outfit and placed it upon a board, as I have suggested, and this board on the north side of the house. While home on vacation I tested this exposure at all hours of the day and night with a sling thermometer, and found the two agreed almost exactly. A careful scrutiny of these observations and comparison with other voluntary records I am sure will show, if anything, a more satisfactory result at Deerfield. Later my father moved to Hartland, Vt., and as my vacation came at that time I set the board upon a maple nearly four feet in diameter. It was in front of a house and about 40 feet away. I feel sure the results here were more satisfactory, if anything, than at Deerfield. Comparisons between the sling and a dry bulb, very near the maximum and minimum, showed the same readings at all hours. I grant that this last exposure on a knoll, higher than all the village about, gave almost a perfect natural ventilation and could not be improved upon. I can not see how any benefit could possibly arise from inclosing the thermometers in a louver shelter, and I can see that the ventilation would be much impeded. I have considered only maximum and minimum above. If dry and wet are used the dry should be close to the maximum and minimum, *i. e.*, to the east, and the wet should be about five inches from the dry and to its left.

In case a voluntary observer has a Richard thermograph I would put it on a board by itself and make the roof extend a little farther over. I would also put the protecting board against the afternoon sun, three or four feet away, and make it large enough to shade the bulb of the thermograph.

Of course the diurnal range of temperature cannot be obtained accurately except in a standard shelter and far above the ground.

EXPOSURE FROM A WINDOW.

Some observers prefer to read their instruments from a window. Professor Snell, of Amherst, made observations from a window for 40 years, maximum, minimum, wet, and dry. A few precautions will give quite accurate results. First, the top window must be fixed so as to open downwards, so that the heat of the room will go above the thermometers when setting them or when wetting the wet bulb.

Lieutenant Mitchell, of Chicago, Ill., years ago, after trying all sorts of experiments, found this the only relief. One of the panes above the thermometers may be hinged, and this will be the more convenient, as well as enabling the keeping in of the heat in winter. The west blind should be securely fastened at right angles to the house, and if there is any eastward "look" to the north side of the house the east blind should be fastened in the same way. A board stretching across the window should be made fast to the window-posts on either side and should be at least one foot from the window—the farther the better, provided the scales of the thermometer are open enough to be read easily. The thermometers should not be nearer than one foot to the window. If there are inside blinds and the light is not needed, they may be closed, but this precaution will not be needed in most seasons of the year. An exposure of this kind is extremely convenient and ought to give good results if properly managed.

H. A. Hazen.

BIBLIOGRAPHY OF THE SUBJECT.

In Europe, Professor Wild has devoted more attention to this matter than any one else; his papers will be found in the "Repertorium für Meteorologie." In England a few experiments have been tried with the Stevenson and Wild shelters. An account will be found in the official publications of that country. Papers are as follows:

Professional Paper No. 18, Science, June 8, 1888, p. 502.
American Journal of Science, May, 1884, pp. 365–378.
American Meteorological Journal, January and February, 1885.
Zeitschrift für Meteorologie, February, 1885.
American Meteorological Journal, October, 1885.
American Journal of Science, December, 1885.
American Meteorological Journal, January and June, 1886.
American Meteorological Journal, January, 1888.

APPENDIX.

The suggestions regarding thermometer exposures here given apply to stations north of 35° north latitude. They may apply a little farther south, but it is evident that the conditions markedly change the farther south we go. A sun which is nearly vertical at noon will shine on the north side of a building nearly all day, and the ordinary precautions will not answer. I do not believe in the East Indian custom of building a horizontal thatch six or seven feet square and then exposing the thermometers in the center with no covering on any side. It would seem that reflected heat and lack of ventilation so near the ground would be objectionable. Exposure at the south needs special investigation. I do not see anything better than an open shelter on the roof of a building.

The experience at Key West is very remarkable as showing the great advantage of good natural ventilation. With the shelter on the north side of the building there were about forty-four 90°-days per year during June, July, and August. With the shelter on the roof there is now only .6 of a day (or three days in five years) in the same months.

APPENDIX B.

REPORT OF THE COMMITTEE ON SIGNALS.

WASHINGTON, D. C., *December* 5, 1892

Major H. H. C. DUNWOODY,
President American Association of
State Weather Services, Washington, D. C.:

DEAR SIR: We have the honor to submit the following report of your committee on signals:

In view of the recent change in the manner of issuing weather forecasts many of the defects of the present system of signaling are obviated, as it is not necessary to display a fair weather flag except in very rare cases, and the subject resolves itself into one of warning only; a rain flag covers the ground fairly well. Several different plans have been suggested for changing the present system of signals, but the matter is so important that no radical change is recommended at present.

The ball or cone system has been recommended by several, and it has some advantages, as has also the semaphore, over the flag system. In special localities flash lights or rockets can be used, it is thought, to advantage. The Pusey system has merits that should receive fuller recognition, as it is simple in its action. The Townsend signal is simple and can undoubtedly be used to good effect, especially in localities affected by coal smoke.

There are submitted with this report papers of several distinguished gentlemen whose views will undoubtedly have great weight in making a proper selection. It will be seen from these reports that a majority favor the ball or cone system. The expense in erecting these will not be favorable to their adoption.

The semaphore signal is considered available for agricultural districts as it can be constructed cheaply and placed at regular distances and operated by the farmers so that the information could be promptly transmitted from each center.

The semaphore signals comprise in a measure the Pusey and Townsend signals above mentioned. Flags cannot be used in many localities on account of coal smoke, which quickly obliterates the colors of the flags. Rockets, flash lights, balloons, and cannon are too expensive for regular use.

Very respectfully,

N. B. CONGER,
S. W. GLENN, } *Committee.*
R. E. KERKAM,

The following papers referred to were submitted by request of the Chief of the Weather Bureau:

WASHINGTON, D. C., *December* 8, 1892.

To the CHIEF OF THE WEATHER BUREAU:

SIR: Referring to the memorandum dated October 25, 1892, requesting that suggestions be made for the improvement of the present system of signaling weather forecasts, I have the honor to submit the following remarks:

The system of flags in use by this service was adopted after careful experiments made by the Indications Board as to the best system of signals, both as to simplicity and visibility. Previous to the adoption of the present system, which depends upon solid colors and position, the flags contained symbols to indicate the weather conditions, these symbols being taken from the Ohio system, which was intended for display on railway trains.

The present system was compared with the drum and cone system by actual test, and in the opinion of the board the flag system proved far superior to the solid symbols. A report of the experiments made by this board will be found in "Extract Number 3, Annual Report of the Chief Signal Officer, 1886," and probably constitutes the only record of an actual test made in this country of the several signals. In all these experiments it has been necessary to provide for at least three elements, viz., fair weather, rain, and temperature, and therefore the system must be more or less complicated. As the present tendency of the service is to allow the absence of the signal to indicate fair weather, it might be well to adopt a system which would only require the display of a rain flag, a local rain flag, and a cold wave flag, thus greatly simplifying the display. I believe the flag to be the best and most practicable signal, owing to its cheapness, although, if funds were available, I would urge the adoption of a semaphore system. It might be possible, also, in localities where electric lights are available, to introduce a flash light in connection with either the storm warnings on the coast, or in connection with approaching storms or cold waves.

Very respectfully,

H. H. C. DUNWOODY,
Major, Signal Corps.

WEATHER BUREAU,
Washington, D. C., October 31, 1892.

To the CHIEF OF THE WEATHER BUREAU:

SIR: In reply to your memorandum of October 25, 1892, relative to weather signals, I have the honor to report that I do not think that any single system of signaling will combine all the features that are desired, viz., cheapness, durability, simplicity, visibility to a greater distance than flags, drums, and cones, and audibility to a greater distance than whistles.

There is such a large variety of information desired by the public that a complex system of signals seems almost inevitable. The amount of information that is now given by signals, and which is, I think, also the maximum that we should try to give, is enumerated in the following paragraph, and anything more than this should, I think, be given by special telegraph or telephone dispatch which may be bulletined in the telegraph and post offices and printed in the daily newspapers—

Weather prediction.	Flag signal.
1. Clear or fair weather	White flag.
2. Rain or snow	Blue flag.
3. Local rains	Half blue half white.
4. Temperature, higher	Black triangle above.
5. Temperature, lower	Black triangle below.
6. Temperature, stationary	Black triangle absent.
7. Cold wave	White flag, black center.
8. Storm flag for special States (blizzards or high winds, snow, and freezing)	Red flag, black center.
9. Storm flag for all seaboard and lake stations (dangerous winds)	Red flag, black center.
10. Direction of storm wind, northwest	White pennant above.
11. Direction of storm wind, southwest	White pennant below.
12. Direction of storm wind, northeast	Red pennant above.
13. Direction of storm wind, southeast	Red pennant below.
14. Cautionary flag for lake stations	Red flag, white center.
15. Direction of cautionary winds, northwest	White pennant above.
16. Direction of cautionary winds, southwest	White pennant below.
17. Direction of cautionary winds, northeast	Red pennant above.
18. Direction of cautionary winds, southeast	Red pennant below.
19. Information signal	Red pennant alone.
20. Frost at special stations	White flag, black center.

In order to diminish the number of signals as much as possible, I recommend that Nos. 4, 5, and 6 of this list be omitted, and that temperature predictions be signaled only when the temperature experiences a decided rise or fall; a decided rise is so rarely injurious that at present it is not worth signaling; a decided fall is only injurious in the special cases of cold waves, blizzards, and severe frosts, and these three I would provide for by special signals, namely, "cold wave," as now in No. 7; "blizzards," as now in No. 8, only I would make it a red flag and black border so as not to be so precisely like No. 9; and for "frosts," No. 20, I would substitute the black triangle as now used in Nos. 4, 5, and 6, but of course putting it below any other signal so as to show that lower temperature is predicted.

The system of items to be signaled is thus reduced from 20 to 17, and the confusion between cold wave and frost, or between blizzard and storm flags, is removed, and a special flag signal for frost is provided.

The remaining 17 items are signaled by means of combinations of 10 different flags, namely:

(a) The white flag.
(b) The blue flag.
(c) Half blue and half white.
(d) White flag and black center.
(e) Red flag and black center.
(f) Red flag and white center.
(g) Red flag and black border.
(h) White pennant.
(i) Red pennant.
(j) Black triangle.

As regards other kinds of signals than flags, I think that if any changes be made they should be in the direction of the "ball, cone, and drum" system, since that is already in use by almost every other nation, but as it would have to be elaborated in order to provide for our 17 items of information, I think it important that only such elaboration should be adopted as is likely to be acceptable to all nations since it is, of course, very desirable that the navigator should find the same system in use at whatever port he may be. As these signals are cumbersome and expensive I would especially direct attention to the utilization of the "semaphore," as used at most naval and mercantile stations throughout the world for telegraphic communication. Semaphores were first established by the French in 1794, and immediately adopted by the English, and are still used wherever the electric telegraph or telephone has not superseded them. Portable semaphores are erected on vessels for communication with shore, and are especially useful when the wind is too feeble to shake out the flag signals. For our purposes the semaphore would consist of a strong mast to which there are attached two arms which are so hinged to the mast that they can be set at any angle by the man who works the ropes at the bottom of the mast. At night these arms carry green, yellow, and red lights. Each arm can be put into five positions, namely, hanging, horizontal, vertical, inclined up, or inclined down, and the combination of the ten positions thus made possible gives an abundant variety of signals. These semaphoric signals are, of course, set up so as to face in the direction that is most important and are equally visible from behind as well as from in front. In some cases we should need to set up another mast with duplicate signals facing at right angles to those on the main mast; the color of the arms of the semaphore will depend upon the background. Thus the signals may be easily and correctly read over the entire region surrounding the semaphore.

If it be practicable to introduce a system radically different from flags and semaphores, then the one that is simplest, cheapest, and thoroughly practical is that which was developed at the Agricultural College at Orono, Me., and which I will call the "staff and balls" system. In this we have at least three balls made of light material painted black and white so as to be easily visible, and whose use as signals depends upon the fact that they have different sizes, for instance, 1, 2, and 4 feet in diameter, respectively, if three balls are used; or 1, 2, 3, and 6 feet if four balls are used. These balls are strung one above the other vertically on the staff; the order in which the balls come as read from above downwards is subject to a large number of combinations, so that with three balls fifteen different predictions may be indicated, the signification of each combination being wholly arbitrary. The balls should, of course, be made of thin slabs or lattice work so as to combine lightness, stiffness, and least resistance to the wind. The most expensive part of this system is the mast and the apparatus for raising and lowering the balls.

In order to make our flag or other signals visible over a wider range of country it is, I think, important to duplicate them at many points surrounding a large city or harbor, and to elevate them higher above the ground than we usually do; this is especially necessary at large ports like New York where myriads of flags and lights surround and obscure our own signals. Progress in meteorology has been greatly forwarded by continuous records from the summit of the Eiffel Tower, and wherever we can obtain the use of similar tall towers for our instruments and signals, there will be a corresponding benefit both to meteorology and to the display of signals.

With regard to signals distributed by means of whistles, bells, and other sounds, I know of nothing better than the steam whistle for those who are within three or four miles of the whistle, and have no other confusing sounds to bother them. But in the cities, where other noises daily obscure the whistle, and where the telegraph and telephone are widely distributed, it should become possible to utilize these latter as well as the city fire-alarm system to disseminate the 11 a. m. prediction daily bell signals, just as the midday time signal is distributed throughout the whole city simultaneously. For instance, adopting a system of bell strokes similar to the long and short whistles, and desiring to communicate to the citizens of Washington the fact that a "cold wave" is expected, the fire-alarm system would, at 11 a. m., be operated from the Weather Bureau, and every gong and bell in the city would ring first a long "Weather Bureau attention call," being a succession of strokes as rapidly as possible for 15 seconds; after this comes a pause and then three sets of rapid strokes (three individual strokes in each set), corresponding to the three short blasts of the whistle. If, however, "fair weather" is to be signaled, then after the "attention call" has been sounded there would come simply one long signal made up of strokes of the bell in rapid succession, lasting for about 5 seconds. In this way we should strike on the fire-alarm gongs in every city where we have an office the same weather signals that are given by the whistles and the signal flags. If now, in addition to this, we display our flag signals at the same time and for an hour or two thereafter at the fire-engine houses, we shall have fully communicated to the people of the cities, before 1 o'clock daily, our ideas as to the coming weather. This utilization of the public fire-alarm system will be especially important if we desire to predict a matter of urgent importance, such as cold waves, blizzards, thunderstorms, and tornadoes.

It will become a regular habit of the people to listen for the 11 a. m. weather signal as they now listen for the 12 o'clock noon signal.

Respectfully,

CLEVELAND ABBE, *Professor.*

WEATHER BUREAU, *October* 31, 1892.

To the CHIEF OF THE WEATHER BUREAU:

SIR: In response to memorandum of October 25, 1892, calling for a report upon a better method of disseminating weather forecasts than that now adopted, I desire to say:

There are at least three methods to be considered, and the one to be chosen, it seems to me, depends as much upon the desires of any community as on any thing.

1st. Visible signals.

2d. Audible signals.

3d. A message to be posted at the post office or other central point from which carriers or criers may distribute the message by horseback, bicycle, or otherwise.

VISIBLE SIGNALS.

For a visible signal I would suggest a dense smoke to be made upon a knoll at a specified time. A white smoke to indicate fair weather or no rain for 24 or 36 hours, as the case may be. A dense black smoke to indicate rain. The smoke should ascend to a considerable height above the trees in a wooded country. If difficulty is experienced in making this visible to low lying districts the smoke may be started in a tree by climbing up a ladder, or in a level country the furnace or smoke producer may be placed upon the roof of a house. Persons interested would very quickly learn where the signal could be seen and would post some one in a position to look for it at the proper time. The duration of the signal is a detail to be decided upon after a little experience and to suit the needs of those interested. I do not now see any difficulty in making the signal *intermittent* for temperature, that is, I would close the furnace or smoke producer momentarily and then open it. The intermittent white smoke would indicate higher, and black, lower temperature.

There is another method which may be simpler yet. Let the duration of the smoke indicate the character of the forecasts, like the flash light in a lighthouse.

For example, *fair* weather, no rain: a white smoke to be seen 1 minute, no smoke, one-half minute; smoke 1 minute, no smoke one-half minute; smoke 1 minute, no smoke one-half minute, three times, and a glance at the watch will show what this means. Persons can tell this, however, without a watch after a little experience, by counting 60. For *rain* I would suggest the same smoke continued for 2 minutes with a gap of 1 minute, three times as before. For *higher* temperature white smoke as for *fair* above, and *lower* temperature the same as rain but with black smoke. This system may be greatly extended. The substances used need not be very expensive; probably they would not cost more than two or three cents each time.

AUDIBLE SIGNALS.

Audible signals would be needed in a hilly country and in dense fog. I would suggest the use of the church bells. These are distributed over the whole country at distances of four or five miles and there are few people who would use the forecasts who are out of hearing of a bell. I do not think there would be much objection to the use of a bell for heralding natures changes provided there are not too many failures in the forecasts. The details of the use of the bell may be easily worked out and very quickly learned by the bell ringer. Church bells are used in this city for the fire alarm, and surely they would be more appropriate for signaling the weather. I would suggest two strokes thrice repeated for fair, three strokes thrice repeated for rain, four strokes thrice repeated for higher temperature, and five strokes thrice for lower. If there is objection to the use of the bell in some cities, owing to its being mistaken for a fire alarm, it will be a very simple matter to settle upon some conventional ringing, as a preface to the forecast, which can always indicate that the probable weather was about to be indicated. I think the definite time of the signal, however, would very quickly impress itself upon the mind and there would be no confusion. It should be noted that this signal would need to be heard only once and not three times to show what it meant.

As an illustration, I note that in this city some churches give three strokes four times repeated each morning at 6 o'clock, and there is no confusion; also, the fire alarm never repeats the same number of strokes.

Another system would be by explosives, but I suppose this may come under the head of rockets, which have already been under advisement. Were it not for the expense and a slight danger connected with this method I think it might be made to supersede all other systems.

The most important thing just now is to improve the forecasts. There is no doubt in my mind that every community where weather forecasts are of value would very quickly devise a permanent system for distribution if it found that the predictions could be depended upon. I would suggest that a carefully worded statement containing the various systems proposed be drawn up in circular form and sent to any community where complaints have arisen or where weather forecasts are desired. Most villages have a flagstaff near the center of the town. At night a Coston signal light might be burned at proper intervals and a sufficient number of times, as has been suggested above for smoke.

I have thought that attention might be attracted to the signal by a loud explosion, from a mortar or otherwise, which need not entail very great expense, just before the regular signal was displayed or sounded. All these matters of detail may be easily arranged after experience and when it is known what can be used to best advantage.

There is one other suggestion. In Pomfret, Vt., there is an enormous tin horn some 20 or 25 feet in length, the volume of sound emanating from this horn is marvellous though blown by lung power. I have no doubt that some device of this kind might be greatly improved upon, and I think it could be heard easily over an area of 40 or 50 square miles. I have heard it 3 miles.

Yours, very respectfully,

H. A. HAZEN.

WASHINGTON, D. C., *October* 29, 1892.

To the CHIEF OF THE WEATHER BUREAU:

Referring to your memorandum of October 25, calling for a report of suggestions of more effectual means for the dissemination of weather warnings, I desire to submit the following remarks:

In your memorandum you have referred in detail to several methods either now used or that have been suggested as useful in this connection and which you say have been thoroughly discussed and are, therefore, debarred from further consideration. In view of this I would say that there appears to be but three methods by which information can be disseminated or acquired. That is to say, an individual may learn a thing which another wishes to impart to him either by *seeing* some signal previously arranged upon, or by ***hearing*** some sound serving as a signal, or he may receive a personal message, which may come to him in a variety of ways.

It seems to me we are confined to one or all of these three methods for disseminating our information. It does not appear to me to be practicable to expect to so improve or extend any of the methods of dissemination depending upon seeing or hearing as to reach a larger class of people than are now reached by those methods. We must depend more, I think, upon the wide dissemination of special messages into remoter regions. These messages have the great advantage of always being more complete and explicit than signals can ever be. Their expense, however, is of course a matter of serious consideration. It is necessary, too, that messages be delivered with great promptness, which implies the use of either telephone or telegraph lines.

There does not appear to be any serious obstacle to sending every community interested in the information some more or less complete message of weather forecasts, and then resorting to the display of signals for the further dissemination to those not already reached. There is little doubt that in many individual cases persons who have any interest in the matter, whatever, can find some means peculiar to their particular circumstances by which they can get regular reports from some adjacent center.

This problem presents extreme difficulties for which I find no satisfactory solution.

Respectfully,

C. F. MARVIN,
Professor, in charge Instrument Room.

OCTOBER 27, 1892.

To Prof. M. W. HARRINGTON:

In regard to the subject of signaling forecasts otherwise than by telegraph and telephone, the following suggestions are offered:

The best method in any particular instance will depend on the locality, what things are to be signaled, and the distance the message is to be transmitted.

Whether the expense of signaling is to be borne by the Weather Bureau or by the communities interested in any special kind of warnings ought to determine largely what method of signaling should be used.

For harbors, where signals are usually viewed at short distances, the cone, cylinder, and sphere constitute the best means of signaling. These symbols have now acquired a definite meteorological significance, their character is established, and they are not used for anything else.

They are separate and distinct from quarantine flags, revenue marine flags, signaling flags, and gala devices of all kinds, and it is considered should be adopted for harbor display.

For population centers inland, in cities and villages where people are clustered in a small area, flags are considered to be the best signaling device.

For long distance signaling where wires are not available, the method to be used ought to depend on who pays for it. If interested communities are willing to bear the expense, the method of carrier pigeons would seem to be the best and surest method of sending messages for distances of five to one hundred miles. It is not recommended that this method be expanded at Weather Bureau expense. If persons interested in specific warnings are willing to pay for the transportation and care of pigeons, which would not be very great, the Weather Bureau could afford to mount them. As a rule, if people are not willing to pay for a thing they have not much use or desire for it, and it ought not to be forced on them.

It might be well to test the feasibility of long distance signaling for special localities by powder flashes. Flashes of half a pound of powder can be seen on clear nights at distances of 50 to 100 miles. The stations have to be intervisible. Probably on cloudy nights places need not be intervisible to have the flashes seen. The flash might possibly be made to carry green or red colors by having the powder contain minute quantities of barium and strontium.

A good plan would be to have an agreed time for making such signals, say 11 p. m., in the case of cold waves, for instance, and the flashes half a minute apart for 10 minutes.

Some experiments might be made on this line, or persons who have done such flashing might be written to. For distant signaling by daylight something might be done by sunlight flashing.

Stations in this case would have to be intervisible and the sky clear. A mirror might be mounted on an automatic whirling device, either by a spring or weight to be wound up or turned by the wind. The mechanism could be made to change the inclination of the mirror to the horizon half a degree at every revolution. This would insure a flash being seen at every part of the horizon at intervals of a minute or so. Such flashes are very readily distinguishable over very great distances.

Very respectfully,

T. RUSSELL.

WASHINGTON, D. C., *October* 26, 1892.

Prof. M. W. HARRINGTON,
Chief of the Weather Bureau:

MY DEAR SIR: Replying to your instructions of the 25th instant, in which you ask me to submit plans for an improved long-distance method of signaling, I am bound to confess, at the outset, that the question is one in which the experience of the practical meteorologist will have every advantage over me.

Nevertheless, I should like to urge at as early a date as possible the use of the "Ballon Captif" in connection with the weather service. It appears to me that the present opportunity is particularly well timed for broaching the matter definitely. I do not aim to offer anything original, my object being rather to present a neglected but feasible experiment.

1. I see no reason why a suitable balloon, a connecting wire, and an efficient reel can not be made at a small expense. Doubtless some preliminary experimentation will be necessary, the object being to devise a form such, that if the balloon is lost, the expense will only be trifling.

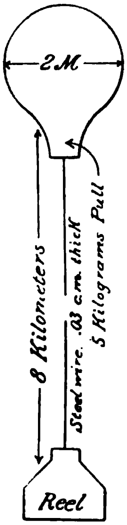

FIG. 5.

To obtain some notion of the conditions involved I will take a homogeneous atmosphere, at 0° C. and 760 *mm.*, a balloon filled with hydrogen, and a steel wire as a tether.

A balloon something over 6 feet, *i. e.*, 2 meters, in diameter, will sustain 5 kilogrammes. This is below the strength of a steel wire $\frac{3}{10}$ millimeters in diameter (sustains 6 *kg.*). Ten kilometers (about 6 miles) of such wire will only weigh 6 kilogrammes.

Hence in a homogeneous, quiet atmosphere such a balloon, if weightless, will go up, say 5 miles, without breaking its cord. Of course the actual case (winds, decreased density of air, etc.) is much more unfavorable, but the margin is large enough to make the experiment worth while. Even a half mile of ascent would offer experimental advantages. Making allowance, however, for the hypsometric correction the ascent of the weightless balloon on the steel wire given should be $8 \div 3.5$ kilometers, or $1\frac{4}{10}$ miles.*

2. *Uses.*—The uses of such a balloon are manifold.

a. It could be colored or shaped in such a way as to be available for signaling forecasts. Here its size is both in favor of visibility and buoyancy.

b. It would be particularly useful for investigating the atmospheric electrical potential, both as regards time and space distribution. (McAdie, Bigelow.)

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* The wire being here superfluously strong the excess of weight can be reckoned as weight of the balloon. Silicon bronze wire, which is nearly as strong as steel and free from rust, would be preferred.

c. It would be of service in mapping out changes of temperature and possibly of pressure on passing from the surface of the earth upward.

d. Finally it would furnish some clues on the motion of upper aerial currents.

3. *Instruments.*—Electrometers suitable for the registry of atmospheric potentials need not be expensive instruments.

A device for anemometry has occurred to me, as follows: The *whistling* made by the wind in passing across a fine wire, *ab*, takes place in accordance with laws which have been exhaustively investigated by Dr. Strouhal. So long as the periods of vibration of the wire are avoided the pitch of the note can be sharply expressed as a function of the speed of the wind. Suppose now such a wire, *ab*, is soldered to the plate of a telephone as in Fig. 6. Then the note can be transmitted to any distance by the telephonic wires, *cd*. This, therefore, is a simple device for anemometry, since the wires are available for transmitting the air potentials and for "captivating" the balloon. Doubtless other means of registry will suggest themselves.

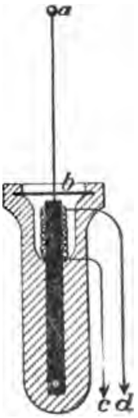

FIG. 6.

4. *General remarks.*—Considering, therefore, the number of uses to which such a balloon can be put, and remembering that some mode of exploring the upper atmosphere *must* be adopted by meteorologists, eventually; remembering too that observations should preferably be made remote from mountains and hills (for the occurrence of earth protuberances of this kind can hardly be without influence in modifying the normal aerial phenomena) the experiment does not seem to be visionary. I am aware, of course, that it is not novel, but it has not, to my knowledge, been reduced to a practical basis.

The construction of a balloon answering the purposes in question is a legitimate laboratory experiment. Parchmentized tissue paper, such as is now much used by draughtsmen, suggests itself for the purpose, since it is toughened and becomes more impervious by exposure to moisture. In fair weather the balloon could be made larger and sent higher. In stormy weather it would have to be smaller, stronger, and more stoutly tethered, and it would not mount as high. If color is an insufficient means of signaling, the form of the balloon is equally capable of variation. Even if untethered, the instrument for signaling would still be an instrument of research in the hands of the meteorologist.

Very respectfully, yours,

C. BARUS, *Physicist.*

WASHINGTON, D. C., *November* 4, 1892.

Prof. MARK W. HARRINGTON,
Chief of the Weather Bureau:

DEAR SIR: Referring to your memorandum bearing date of the 25th ultimo, with request for opinions and suggestions looking to a more perfect system of signaling forecasts, with special reference to the outlying agricultural districts, distant from cities and towns by from 5 to 25 miles, I beg leave to submit the following:

During the present year it has been my privilege, in the line of duty, to attend a considerable number of farmer's gatherings in widely separated States of our Union. Coming thus in close touch with so many who are directly concerned in the matter, I had frequent opportunities for noting the work of the present system of signaling and for hearing from those who were more or less benefited by the service.

I have found that the efforts made during the year to extend the benefits of the Bureau in the rural districts are heartily appreciated. A general interest prevails among the farmers to learn more of the methods of work of the Weather Bureau, and a desire to avail themselves of its advantages. Those who have been so favorably situated that they could promptly receive the forecasts are enthusiastic in their appreciation of the work and its great value in their farming operations.

Upon the present lines of work, and with the methods of signaling now in use, there yet remains a large amount of uncovered territory.

In some sections, through concerted action of farmers, fruit and vegetable growers, and others, the use of a cannon, specially for frost warnings, has proven satisfactory. In some localities this method of signaling, if not already tested for more general use, might be at least experimentally extended.

I am more and more convinced, as I go over the field and consider the whole situation, that the full benefits of the Weather Bureau service can never be received by the great majority of our farmers, and by the dwellers in remote villages and hamlets, until one or both of the following steps of progress are taken.

1st. The establishment of at least one Government telegraph or telephone station in each county of the United States, and, if possible, this central station—which may very properly be the county seat—should be in connection by telephone with each *local* post office in the county. To this central station the Washington, D. C., general and State local forecasts should be promptly forwarded at least twice in twenty-four hours, with provision for "extras," such as "cold waves," frosts, local storms, etc. With the prospective expiration of the general patents on the telephone, the instruments will be greatly cheapened, and there is scarcely a neighborhood where the farmers would not co-operate in purchasing the instruments and erecting the few miles of poles and wires needed to connect their houses directly with the local post office, or, if need be, with the central station at the county seat; not only to receive the great benefit of the prompt receipt of the weather forecasts, but for all the many other advantages which close contact with the markets and the events of the world of the day would afford them.

2d. A general and systematic extension of the rural free delivery of the mails, by which the farmers along these country post routes could receive either their daily paper containing the forecasts or a special farmers' weather bulletin sent out from the nearest local Weather Bureau station. Or this rural mail carrier might have displayed upon his wagon, horse, bicycle, or pouch, a flag, or other signals furnished him each day at his starting point.

I believe that as the great benefits farmers, who are so much dependent upon the weather for their success, can derive from the Weather Bureau service become better and more generally known, that a public sentiment and demand will be created which will eventually result in one and probably both of the above suggested plans. To this end every effort should be made to extend and perfect the present system as far as possible, every new locality reached by flags or whistles becoming the leaven that will in the near future leaven the whole lump.

Very respectfully,

MORTIMER WHITEHEAD, *Inspector.*

WASHINGTON, D. C., *October* 31, 1892.

To the CHIEF OF THE WEATHER BUREAU:

SIR: Replying to memorandum dated October 25, I have the honor to state my belief that no system of *visual* signals can possibly be devised that will meet the various requirements of communicating the forecasts to the "outlying agricultural districts." The cost alone is an insurmountable obstacle unless those directly benefited will bear the expense. The same would probably prove to be the case with any system of *sound* signals, though it might be well to investigate the probable cost of announcing forecasts of *severe* storms or *severe* cold by means of explosives set off in the early evening (say about 6 o'clock) when the warnings are to be given for the next day. A few pounds of some quick burning explosive suitably placed, or confined so as to produce vibrations in both air and earth, would give warning to a very extensive area, and in such manner as to attract attention from all persons within the radius of vibration. I would suggest one explosion for rain or snow storm, two explosions in quick succession for *severe* storm with rain or snow, and two explosions with 15 or 20 seconds interval for severe and sudden fall in temperature, or for frost. I think any system of weather signals should announce only the unusual and abnormal features; the absence of the signal should indicate "fair," or that "nothing unusual will occur."

As to the daily announcement and dissemination of the 36-hour general forecasts for the benefit of the agricultural districts, I believe it can only be successfully accomplished through and with the hearty co-operation of the Post Office Department and by means of the press.

Nearly all farmers in these days, especially those near small villages or towns, visit or send to the nearest post office every day, and a very large percentage of them read a daily paper. I therefore suggest:

1st. An appropriation (specific) for the necessary telegraph and telephone messages (nearly every region can now be reached by one or the other).

2d. Furnish each postmaster with a simple announcement by wire of the probable weather for the next day in the fewest possible words. Thus: "Monday 31, rain;" or "Monday, 31, rain in afternoon;" etc. The date might be omitted, perhaps, and simply the day of week used. Let it be understood that the absence of the telegraphic message shall mean "fair," and the cost can be much reduced.

Then provide large sheets with suitable head lines on which the postmaster shall write, *with crayon*, the weather announcement, and post it on the regular bulletin boards of the post office.

Let it be once *well understood* by the farmers that the Government daily telegraphs the forecasts to each post office, and the people will generally avail themselves of the opportunity thus given to know of coming changes in weather.

Very respectfully, your obedient servant,

B. M. PURSSELL,
First Lieutenant, 19*th Infantry.*

WASHINGTON, D. C., *October* 28, 1892.

To the CHIEF OF THE WEATHER BUREAU:

SIR: Referring to memorandum dated the 25th instant, reciting defective features of the present systems of weather forecast signals, and calling for opinions and suggestions calculated to remedy the defects, and also to extend the benefits of the forecasts to agricultural districts remote from telegraph and telephone lines, I have the honor to report as follows:

DISPLAY SIGNALS.

Flag signals are, in my opinion and experience, very unsatisfactory. Few persons know or remember the combinations, and the system is expensive.

Whistle signals have the same objection as regards the combinations, and, in addition, they cannot be depended upon for large areas, owing to variability of wind direction.

The ball, drum, and cone system is, in my opinion, the best. Form and not color must be depended upon for satisfactory service. The distinctiveness of the signals of this system is independent of the wind force and direction, and they do not become indistinguishable as a result of deposits of dirt, soot, etc. They are also durable, and, unlike the flags, there would not be a constant expense for new material.

TRANSMISSION OF FORECASTS.

The mail service can be utilized only for small areas about the map or bulletin distributing centers. The telegraph and telephone present the only medium of communication with districts remote from forecasting stations.

In my opinion the greatest possible number of post offices having telegraphic or telephonic communication should be made display stations. Co-operation with the Post Office Department would make the prompt display of signals and the care of the signal material a part of the official duty of the postmaster.

SUGGESTION.

My suggestion for improving the system with the facilities at present available is that form signals, say the ball, drum, and cone, be used instead of flags. I would also suggest that in case the Post Office Department can be induced to co-operate, form signals and the apparatus necessary for their display be furnished postmasters who can be reached by telegraph or telephone, and that signals be displayed upon postal cars.

By this plan the weather signal system would be co-extensive with the growth of the telegraph, telephone, and railway lines. The postal car signals would reach many districts remote from telegraph offices and towns or villages early in the day. These signals could be placed, if necessary, by observers at forecasting centers.

Very respectfully,

E. B. Garriott.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 8.

REPORT

ON THE

CLIMATOLOGY OF THE COTTON PLANT.

BY

P. H. MELL, Ph. D.,
Professor of Geology and Botany in Alabama Polytechnic Institute;
Director of Alabama Weather Service.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., December 15, 1892.

Sir: I have the honor to transmit herewith a report on the "Climatology of the Cotton Plant," by Prof. P. H. Mell, of the Alabama Polytechnic Institute, and to recommend its publication as Weather Bureau Bulletin No. 8.

Very respectfully,

Mark W. Harrington,
Chief of Weather Bureau.

Hon. J. M. Rusk,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

ALABAMA POLYTECHNIC INSTITUTE,
Auburn, Ala., August 9, 1892.

SIR: I have the honor to submit herewith a report on the "Climatology of the Cotton Plant," prepared at your request.

Very respectfully,

P. H. MELL,
Professor of Geology and Botany.

MARK W. HARRINGTON,
Chief of Weather Bureau.

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CLIMATOLOGY OF THE COTTON PLANT.

INTRODUCTION.

The botanical question relating to the cultivation of cotton has been one of great interest to the writer for a number of years, and he entered upon the study of the climatology of the subject with more than an ordinary degree of pleasure. As the work developed, however, it became more and more apparent that limited time and the vast array of meteorological data would prevent anything more than simply an introduction to the study of cotton and its climate.

It is proper to say that in the collection of the data for the writing of this pamphlet liberal use has been made of numerous United States Government reports and publications, the files of the "Commercial and Financial Chronicle," many agricultural papers and magazines, and books relating to the cultivation of cotton in the United States and in foreign countries. Valuable advice and counsel have also been rendered by Dr. J. T. Anderson, assistant state chemist of Alabama, and valuable assistance in the preparation of meteorological data.

The following planters and meteorological observers and scientists have also furnished useful information: From Virginia, J. N. Ryker, assistant director State Weather Service, R. V. Gaeves; from South Carolina, W. J. Hinson, E. R. McIver, Dr. A. P. Battle, director State Weather Service, J. A. Peterkin; from Georgia, J. K. Dixon, H. W. Blount, Col. R. J. Redding, director Agricultural Experiment Station, J. A. Law, S. E. Lewis, J. A. Chapman, D. M. Wade, R. L. Rhodes, J. F. Wilson, Park Morrill, director State Weather Service, S. M. Barnett, J. L. Cutler, S. A. Cook; from Florida, Livingston Vann, E. R. Demain, director State Weather Service, H. W. Long, Dr. J. P. DePass, director Agricultural Station; from Mississippi, R. J. Hyatt, W. E. Butler; from Louisiana, D. N. Harris, L. J. Dodge, W. W. Wall, Dr. W. M. Guice, Dr. E. A. Crawford, G. E. Hunt, director State Weather Service, Prof. W. C. Stubbs, director Agricultural Station, G. W. Whitworth, L. D. Martin, A. F. Thanpeau, M. J. Wright, jr.; from Tennessee, G. W. Lasater, Prof. C. F. Vanderford, assistant director Agricultural Experiment Station, J. B. Marbury, director State Weather Service, C. W. Anderson; from Texas, Prof. Duncan Adriance, meteorologist Agricultural Experiment Station; from Arkansas, R. L. Bennett, director Agricultural Experiment Station, E.

H. Clarke, assistant director State Weather Service; from Missouri, J. H. Smith, assistant director State Weather Service.

I.—HISTORY OF THE COTTON PLANT AND ITS SPECIES.

The cotton belongs to a large family of plants called Malvaceæ, and is represented by more than fifty species. Only about six or eight of these species, however, are of special commercial value, and from these the fiber of the world is produced. Among this number may be mentioned the following as representing the most important:

1. *Gossypium bahma*, or Egyptian cotton.
2. *Gossypium barbadense*, also called *Gossypium nigrum*, sea-island cotton, long-staple cotton, and black-seed cotton.
3. *Gossypium herbaceum*, also called *Gossypium album*, short-staple cotton, upland cotton, and green-seed cotton.

These species have been again divided into a large number of so-called varieties, that have been produced by accidental crossings between species exposed to each other in neighboring fields years ago, until now, under peculiar conditions of cultivation and changes of climate the specific characteristics have been largely concealed, and it is somewhat doubtful whether the upland cotton is *Gossypium herbaceum* or the mingling of several species.

Gossypium bahma originated in Egypt many years since, and was produced through an accidental hybrid from the *Hibiscus esculentus* with the native Egyptian cotton.

The *Gossypium barbadense*, or sea-island cotton, came originally from Persia, from which country it was transplanted to the Island of Anguilla, then to the Bahama Islands, and subsequently to the coasts of South Carolina and Georgia and East Florida. This plant has been grown with various degrees of success for many years on the islands of Edisto, Saint Simons, Jekyl, and Skidaway; but it has never reached that degree of development and extent of cultivation that has been accorded the upland cottons.

The *Gossypium herbaceum*, or green-seed cotton, is the name generally applied to all plants grown in the interior of the cotton belt, although I am inclined to the belief that an investigation will prove that the upland cotton is the blending of several species. It is quite difficult to give the exact origin of the *Gossypium herbaceum*, as many sources have been claimed for it. Some of the authorities have referred it to an offspring from the Brazilian cotton, while others with equal positiveness assert that it came from the Mexican stock, and hence have given it the common name of "Mexican cotton." There is every reason to believe, however, that the plant has long been acclimated to its present home, and, as already stated, has undergone many changes that have been brought about largely through climatic conditions. From its more or less shrubby form, it is supposed by some authorities to have been tree-like in its early history and not an annual as it is now. In support of this idea it is well known that in some portions of the cotton belt the plant assumes sometimes almost the size of a tree and its stem becomes decidedly shrubby. Its habitat, however, over the entire South has reduced it to an annual, and the seed is planted and the fiber is matured between the last frost of spring and the first frost of autumn.

It is said by those who claim that the original plants came from Mexico, that in the early part of the present century the United States Minister then at the court of Mexico noticed this species of cotton growing in a comparatively wild state in that country, and whenever it was subjected to cultivation the resulting fiber was long, white, and beautiful. He requested permission of the Mexican Government to transport some of the seeds to his country for the purpose of experimenting with it to determine if it could be successfully grown in the United States. This request was refused. At a state dinner subsequently, however, the subject of cotton and its cultivation was introduced, and in the progress of the conversation the minister was informed that no objection would be raised to his exporting as many dolls to his country as he might desire. He immediately took the hint, and had a large number of dolls stuffed with the cotton seed and lint that he succeeded in securing from the most healthy and vigorous plants. These dolls were sent to Washington and the cotton seeds were distributed over the Southern States, and in years after became the cotton plant of the South. The accuracy of this incident is not vouched for, but it has received considerable credence in the southwestern portions of the cotton belt, and it is simply given as a matter of interest in this connection.

It is also stated by a few authorities that the *Gossypium herbaceum* came originally from the coasts bordering the Mediterranean and from portions of Asia Minor. From a speech delivered by W. B. Seabrook, president of the South Carolina Agricultural Society, in 1843, the following extracts are taken as interesting in connection with the discussion of the origin of the green-seed cotton:

> As a preliminary point it may be asked whence came the seed of this cotton, now so extensively cultivated in the United States? This question is probably not susceptible of a positive and unexceptionable answer. That it was not brought from India is perhaps obvious. The policy of the East India Company, who obtained their monopoly in the year 1600, was unquestionably adverse to the exportation of cotton seed. Individuals would scarcely have deemed it necessary to draw from the distant East that which was obtainable much nearer home, and of a quality, too, greatly to be preferred. As the trade in the raw material, during the larger portion of the period alluded to, was confined to the Mediterranean, it was a legitimate inference, in the absence of positive proof, that from that quarter the nations of Europe owning possessions in the western hemisphere respectively introduced into them the new culture. This, perhaps, was especially true of the Low Countries and of England, as in 1560 the former constituted the depot for cotton goods from the Levant; and the Turkish trade, of which

Smyrna was the seat, was at the time of which we speak the most important to the latter. Peter Purry is represented to have brought with him, among other seeds, that of cotton. [Peter Purry settled in South Carolina in 1731, during the administration of Governor Robert Johnson.] This, and a paper of the same material received by the Trustees for the settlement of Georgia, from Phillip Miller, of Chelsea, England, it can be scarcely questioned, were from the Mediterranean. In a pamphlet entitled "American Husbandry," published in London in 1775, the writer remarks that "the cotton cultivated in our colonies is of the Turkish kind." On the other hand, it must be supposed from the language of their historian that the Cape Fear emigrants, who began the growing of the *gossypium* only two years after they had established their settlement, were provided with seeds from Barbadoes. The vicinity of the West Indies, the profitableness of the cotton crop, the varieties of the plant, which at an early period were cultivated in those islands, all render it nearly certain that from thence was drawn a portion of the supply with which the people from time to time were provided.

Between 1786 and 1795 cotton from various parts of the world was introduced into the Southern States and Louisiana. A species of the white Siam was for some time the subject of experiment by the French in the latter country. The "Nankeen" came from Malta. The "Bourbon" was brought from that island to Charleston through the instrumentality of James Hamilton, who was a merchant and part owner of the only India ship at that time trading beyond the Cape of Good Hope. The "Pernambuco" or "kidney cotton" was sent from Havana to Mr. Levett of Georgia, by a Mr. Welch, a merchant in Philadelphia. These, and many other sorts, after a fair trial, were abandoned, for the reason of their inferiority to the kinds then profitably raised, viz., the real green seed and the black seed or sea island cotton, the latter having superseded the plant that was grown at the period of the Revolution, which strongly resembled the short staple in growth and blossom, except having a clear black seed with fur at the end. From this brief notice of the quarters whence different cottons were received in this country we have satisfactory reasons for concluding, that to the Mediterranean and Asia Minor we are mainly indebted for the particular species of *gossypium* which has been the subject of investigation. Of the two kinds from which the green seed is derived, the *herbaceum* is clearly of Eastern origin, and the *hirsutum* also probably, though it is positively asserted to be a native of the West Indies.

From all the testimony presented on the subject of the origin of the present green seed cottons, from which nine-tenths of the staple of the South is obtained, it seems more than probable that this plant is the result of frequent hybridizing between various species of the *gossypium* through a long period of years. The peculiar soil of the South, together with its characteristic climate and the methods of cultivation universally used by the planters for more than one hundred years, have much to do with changing the plant to what is now known as *Gossypium herbaceum.* What the plant was when first introduced we can only conjecture; nor can it be positively asserted that it is not indigenous to the South. That it has undergone great changes within one hundred years there can be no doubt, as is well indicated by the large number of so-called varieties that have been brought before the farmers within the past thirty years. That climate has had much to do with this no one can deny.

Thirty or forty years after the first authentic cultivation of the green seed cotton, some farmers living in the State of Mississippi, near the Mississippi River, discovered that under peculiar methods of cultivation the plant would thrive and produce a very superior grade of fiber. They also found that by carefully selecting the seeds from these special plants and planting them under the best conditions the quality of the fiber was greatly improved. This method gave rise to the first variety of the upland or green seed cotton that was named "Petit Gulf," after a little quiet bay formed by the Mississippi River in that State. The demand for that seed became great at once, enriching the farmers who first handled it, and encouraged other planters throughout the South to experiment, until now there are more than thirty so-called varieties known.

THE EXTENT OF THE COTTON BELT.

At the opening of the war between the States in 1861, the cotton region of the United States included South Carolina, Georgia, and Florida north of latitude 27°, Alabama, Mississippi, Louisiana, southern portion of Tennessee, Arkansas south of latitude 35°, and Texas between the Gulf of Mexico and 34° north latitude. A small part of North Carolina might also be included in this area, but in this State the planting and cultivating of cotton was quite limited in 1858. Up to 1860 this belt was being gradually extended east, west, and north. In the east it had reached the coast of North Carolina and had extended westward as far as some of the southwestern counties on the Rio del Norte in Texas. The planting in Tennessee had not extended much beyond the middle of the State. The counties lying immediately around Memphis were generally considered to have the best soils for this purpose, and prior to 1860 produced the largest proportion of the cotton raised in Tennessee.

The line running across the United States a little north of the thirty-sixth parallel will about designate the northern limits of the cotton region at the close of 1860, and the southern limit about coincided with the twenty-ninth parallel (see Chart VII). After the close of the war, when the high price of cotton stimulated its cultivation, the farmers, not only throughout the belt already indicated, but planters beyond the northern limits, cultivated large areas and attempted to force the plant to perfect its fruit, by the use of fertilizers, before the occurrence of frosts. But all attempts to carry the cultivation of cotton much beyond the State of Tennessee have proved failures, and to-day the cotton belt is not materially extended beyond what it was in 1860.

Chart VII, copied from the Tenth Census, vol. 5, shows the extent of the cotton belt in 1882. The shading gives the varying intensity of cotton culture as compared with the total land area. In commenting on this map Dr. Hilgard, the special agent for the Census Bureau, says:

> The regions of high percentage devoted to cotton (10 to 20 per cent. of the total area)

are confined almost exclusively to the central portions of Mississippi, Alabama, and Georgia, the cotton acreage averaging above 65 acres per square mile within the respective areas. Small patches (representing counties) of the same occur in North Carolina, Tennessee, and Texas.

Regions of maximum intensity of cotton culture above 20 per cent. of the total area form two prominent belts (shown by the deepest shades of color) one lying along the Mississippi River within the alluvial region, while the other embraces the black prairie region from northeastern Mississippi, southeastward nearly through the central portion of Alabama. The cotton acreage within these belts averages 130 acres per square mile, and upon them was produced in 1879 about 753,550 bales of cotton. A penumbral region of very sparse culture is seen almost to surround, both inland and along the coast, the cotton-producing portion of the States, while outlying areas (representing isolated counties) occur in Kentucky. Cotton culture in Florida is chiefly confined to that part of the State lying adjacent to Georgia. This is mostly pine land, and is cultivated without manure; hence the low product of less than a quarter of a bale per acre. No cotton is returned from that portion of the state lying south of Tampa Bay, and but little from the coasts, as well as from the extreme western part. A considerable proportion of this product is long-staple or sea-island cotton, of which the State produces nearly the entire supply at present. The cotton production of Tennessee is concentrated upon a comparatively small area of highly productive lands, the rest being devoted preferably to grain, grasses, tobacco, and other industries, to which the soils and climates are more specially adapted. A discussion of the returns shows that 52 per cent. of the cotton product of Texas is grown in the northeastern portion of the State, north of the thirty-second parallel and east of the ninety-eighth meridian, and that within this region the production is highest in the counties adjoining Red River, the product averaging 0.54 bale per acre. South of the thirty-second parallel the average yield is 0.34 bale per acre. The coast counties produce but little cotton; inland, between Red River and San Antonio, about 34 per cent. of the total product is grown on black prairie land.

In another part of the volume above mentioned, Dr. James M. Safford, in writing concerning Tennessee, says:

The latitude of Tennessee is such that a fall of two degrees of temperature in the northern part of the State might cause a killing frost, resulting in the destruction of the cotton plants, while the same fall in the southern part would leave them intact. The length of the growing season for cotton is, at the best, short enough in the southern part of the State, and where so slight a change of temperature produces such results we can readily see how in the northern part it may be generally too short for full crops, which in reality it is. It amounts nearly to the same thing to say that the margin of the cotton-growing section of the country runs through Tennessee. In an inspection of the map showing percentage of aggregate areas in cotton, as compared with the entire area of any given region, it is seen that the counties in Tennessee which plant and produce the most cotton are strikingly the most southerly ones, and that from these the production decreases almost uniformly as we go north. This is especially so in West Tennessee. Now, in explanation of this, in part, at least, it is to be noted that the isotherms, or lines of equal temperature, for spring and fall extend west-northwest through the State, say parallel with a line running through Chattanooga and Trenton or thereabout. This shows the southwestern corner to be the warmest, and here is our greatest center of cotton culture. The greater warmth stimulates the cotton, and by throwing back the killing frosts increases the length of the growing season. The soils have their influence, but that they are not dominant in this distribution of percentage culture is shown by the fact that as we go north the decrease occurs, though the soils and elevation remain essentially the same. It is also noteworthy that as we go eastward from each of the two centers of cotton culture (the southwesterly corner of the State and the southern part of the central basin) the percentage of cotton culture rapidly decreases. The temperature and higher elevation obviously have much to do with this decrease.

Dr. R. H. Loughridge, in the same work already quoted from, makes the following comments concerning the extent of cotton growth in Texas in 1880:

> In 1869 the region of cotton cultivation extended nearly half way across the State from east to west, and embraced in its limits about 108,000 square miles, or about 41 per cent. of the land area. A line marking its western limit would pass southward from Red River, through the counties of Montague, Wise, Parker, Erath, and Hamilton to Atascosa, and thence eastward to Matagorda County.
>
> A line marking the limit for 1879 would pass from Red River, in Wichita County, southwest into Jones and Taylor, and south through Coleman, McCulloch, Mason, Kerr, Bandera, and Uvalde to the Nueces River, which it would follow nearly to the Gulf. Small spots of cotton production (49 acres altogether) occur also on the Rio Grande in Cameron and Hidalgo counties.

As will be hereafter shown, there is no reason to believe that the area of the cotton belt has extended much beyond the western limit given by Dr. Loughridge in the above extract. We may, therefore, conclude that the outlines on the map practically limit the cotton belt in 1891. The penumbral shades are of little importance in the discussion of the climatological effects on the cotton, because these outlying areas are only the sections where the cultivation of the plant is conducted under the most favorable conditions of the seasons. It must be understood that these exceptions apply only to the extreme northern and western limits and not to the lighter shades located in the interior of the cotton belt. Here other causes must be considered to explain the small production of the staple. Among the number may be mentioned the character of the land as well as the elevation.

The use of commercial fertilizers has greatly improved the qualities of the cotton and made it possible to cultivate lands that were heretofore considered inadequate to the demands of the plant. Before the late war it was the custom among southern farmers to cultivate a piece of land until its natural resources were about exhausted and then clear up a new piece from the native forests that then covered the largest portions of the Southern States. The old fields were turned out to grow up in pines or left to waste still more under the influence of the washing rains of winter, until the whole cotton region in 1860 seemed to be one vast belt of exhausted, badly washed lands. Since the use of fertilizers became so universal, however, attempts have been made to reclaim these wornout lands, and to-day many plantations in South Carolina, Georgia, and Alabama, that were cultivated in 1865 and considered to be practically ruined, have now been almost reclaimed and under favorable conditions are producing nearly as good results as when in their virgin state. This has been brought about by the restoration of the cotton seed to the lands as well as in the use of commercial fertilizers.

It must not be understood from what has been said that all lands in the cotton belt prior to 1860 were used for cotton culture, but, on the contrary, it was found by experience that certain soils were better adapted to its growth than others. For instance, the "Black Belt" of Alabama, or the cretaceous formation, that passes across the middle portions of the State, monopolized the cotton cultivation in that portion of the South and little cotton planting was done outside of that region, or north of the thirty-third parallel. These lands were so rich in all the elements that perfect the plant that it was deemed unnecessary, until within the past few years, to use fertilizers of any character. The production was generally a bale to the acre and sometimes as much as a bale and half to the acre. But the constant cultivation of these lands without returning what had been taken from them has greatly impoverished what has heretofore been considered to be the richest and most valuable property in the world. The planters are now beginning to use fertilizers in this region and an effort is being made to restore the lands to their former remarkable productiveness. Dr. Hilgard, in speaking of these soils, says:

> From the Chattahoochee west to the Nueces River of Texas, calcareous soils are widely prevalent; and the parallel map of intensity of cotton production shows a marked increase of the cotton culture whenever one of these calcareous belts is reached.
>
> East of the Chattahoochee and northeastward to the James few prominently calcareous soil areas are met with, and all such are rather local and of small extent. The soils here, being derived from the eastern slope of the Alleghanies, are prevalently of a light siliceous character, and below the break of the highlands into the coast plains (or what is popularly known as "the falls of the rivers") they are but rarely influenced by the underlying tertiary marls. They are mostly what in a wide application of the term might be termed "alluvial" soils, chiefly of early quaternary origin; and, aside from the narrow "live oak belt" of the immediate coast, the long-leaf pine is their characteristic tree. This pine, as analysis shows, is everywhere an indication of soils poor in lime, and experience shows that until the use of fertilizers becomes part of the agricultural system only the bottom lands of a long-leaf pine area are usually utilized for cotton production. Hence the great pine belts of the Gulf coast produce but very little cotton, while on the Atlantic border, with the use of fertilizers, the culture is more extended.
>
> Inland the proportion of lime in the soils usually increases, and correspondingly the long-leaf pine gradually gives way to the short leaf species and an increasing proportion of oaks and hickories, until finally the latter only occupy the ground. With local modifications, this order of things holds good pretty generally from Virginia to eastern Louisiana, but by far most strikingly so in the Gulf States east of the Mississippi. In the bottom plain of the latter, near the line between Arkansas and Louisiana, we find the maximum cotton production on natural soils on the highly calcareous and otherwise also profusely fertile "buckshot" soils of the great valley, with which only some of those of Red River bottom can dispute precedence. Under their influence cotton cultivation is carried far into Missouri, while in the hill country to the eastward and westward, in Kentucky and in northwestern Arkansas, it forms but a subordinate feature. In Texas again the tertiary and cretaceous prairie regions produce the bulk of upland cotton, while in the coast prairie region the river bottoms are almost alone employed in its production thus far; and westward of the cretaceous prairie region, where the rainfall becomes more scanty, it has not yet had time to establish itself on a permanent footing, save locally.

In other portions of the South the lands selected by the planters in

1860 as those best suited for the production of cotton were those of a soft, deep mold in which the color was darkened by a due admixture of decaying vegetable matter, a medium between spongy and sandy soils. These lands were generally found on creek and river bottoms. So it must be remembered that although cotton was planted on every plantation in the cotton belt, still there was a large proportion of the land throughout the country that was considered poorly adapted to its cultivation. It is now generally understood that any land in the belt that contains the necessary ingredients in an available form, and that is well drained, can be made to produce excellent grades of cotton. The loose, sandy soils of the coast regions, that were formerly thought to be unfit for profitable cotton culture, are now producing well under modern treatment. This may be said with equal force concerning the heavy clay lands of the hilly regions.

II.—A GENERAL DISCUSSION OF THOSE COUNTRIES WHERE COTTON IS CULTIVATED TO ANY EXTENT.

In the discussion of the question of climatic effects on the growth and successful cultivation of cotton, it will be interesting to compare the climates of those countries where the plant seems to be indigenous with that of the Southern United States. I have selected for this purpose some of the most important of those countries where climatic data are available.

In making this comparison special attention is called to the fact that in no other country do we find such uniform distribution of rain throughout the year as we note in this southern land. And the gradual changes of temperature here during the summer months are more advantageous to the well-being of the tender cotton plant than are to be found in any other country on the globe, so far as the writer knows. It is unfortunate, however, that more extensive meteorological data from these foreign countries where cotton is cultivated can not be secured so as to bring out the points of comparison in more striking manner than is possible with such meager reports.

WEST INDIES.

The temperature in this country ranges between 77° and 82°, and frosts are but seldom known. A short wet season begins in April and lasts from two to six weeks, followed by a dry season, when the thermometer remains almost stationary at 80°. The heat is very oppressive during July and August, and the summer is very dry. The great rainy season begins October 1 and lasts until December, when a dry spell follows, lasting until April 1. The annual rainfall is 63.00 inches. At Barbadoes the following record of temperature has been secured that shows very uniform results:

	°		°
January	78.0	September	82.1
February	78.0	October	82.2
March	79.1	November	81.8
April	78.2	December	79.3
May	79.6	Spring	79.2
June	78.1	Summer	78.5
July	79.0	Autumn	82.1
August	78.5	Winter	78.5

The mean annual temperature is 79.5°. The maximum is 87° and the minimum is 75°. The annual rainfall is 57.74 inches.

BRITISH INDIA.

It is thought that cotton is indigenous to the soil of this country. The cultivation has been carried on for many years with various degrees of success. It is believed by some authorities that the cotton plant came originally from this country, passing through Persia, Arabia, and Asia Minor, and probably to America. Upon this point, however, there is much doubt.

Commissioner Young, in his account of the cotton industry exhibited at the Paris Exposition in 1878, comments as follows concerning the cotton in India:

> The samples of cotton from Mahratta, in India, and Dharwar, attracted my attention, as they seemed to be superior to most of the other Indian cottons. They are clean, bright cottons, but, like most of the Indian cottons, coarse and short. From this exhibition I learned that the cotton of all or nearly all of the Indian provinces has been greatly improved by the introduction of American seed. It was in Dharwar that our American planters obtained the greatest success, and I am told that the entire crop in this province is now from seed originally American. These districts are reported to enjoy a climate resembling that of the American Gulf States, never excessively dry and never overflowed with excessive rains. In 1844 there were, it is said, 1,200 acres planted in American seed; in 1848 between 18,000 and 20,000; and in 1860 the crop was said to be over 2,000,000 pounds. When the American war of secession seemed inevitable, England proposed again to husband the production of cotton in India, for it appears that, for some reason, the American planters who had been employed years previously to instruct the people of India in the culture of cotton had left the country and returned to their homes, and that after their departure the production seemed to diminish. while the improved implements of agriculture which had been introduced by them had been thrown away, or at least passed out of use by the natives. One author states that some English plows were introduced by the agent, when at first the natives were greatly astonished at their results and admired them extravagantly; but when the agent turned his back they painted the plow red, turned it up on end and worshiped it, and returned to the use of their original clumsy utensils. The attempts of England to produce her own supplies of cotton from her own territory, and thus become independent of the product of America, seem to have been a failure. Nor has the experience in India been exceptional, for about the same period an attempt was made to extend its cultivation to Africa.

This country is one of the most important outside of the United States that is now engaged in the cultivation of cotton, and a meteorological comparison, therefore, will be interesting in the discussion of the subject now before us.

The seasons in India are naturally divided into cold, hot, and rainy periods. The stations in different parts of the country give very marked differences in temperature and rainfall. The climate is greatly influenced by the two monsoons that blow from the northeast and southwest. Great extremes of temperature and moisture precede and accompany these monsoons, so that the cotton plant suffers very much under the trying changes. All India does not suffer so greatly under the influence of these monsoons and the cotton plant in some sections gives very good results. For the purposes of this paper the following stations have been selected as occupying the most important parts of the cotton region of that country:

TABLE I.—*Mean temperature of several stations in India.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Elevation.
	°	°	°	°	°	°	°	°	°	°	°	°	°	*Feet.*
Singapore	86	88	89	85	85	87	88	86	87	87	86	85	86.6	Sea.
Madras	75.5	77.7	80.8	83.7	86.8	87.7	85.3	84.6	83.7	82	78.9	76	81.9	Sea.
Calcutta	66	69.8	80	85.4	85.7	83.7	81.8	82	82	79.2	74.2	66	78	Sea.
Benares	62.6	72.5	79	89.9	94.4	90.3	85.7	85.7	86	81.5	72	64	80.3	300
Cawnpore	63	69	72.2	88.0	96	91.2	86.7	87	85	79	75.3	67	80	500
Surouli	51.4	59.3	67.2	75.0	82.5	87.8	88.6	88.9	77.8	72.3	60.3	49	71.7	800
Seharunpoor	52.1	63.3	68.0	79.0	86.1	89.0	86.8	85.3	78.0	74.0	64.8	56	73.5	1,000
Dehra Doon	52.1	59.1	67.0	73.0	81.0	86.0	83.0	81.0	78.1	73.1	57.0	56	70.5	2,350

TABLE II.—*Annual precipitation at certain stations in India.*

Stations.	Amount.	Stations.	Amount.
	Inches.		*Inches.*
Bombay	68.73	Colapoor	30.74
Butnagherry	114.55	Poonah	19.02
Tanna	106.16	Nassuck	26.72
Dapoolee	134.96	Belgaum	40.90
Kundaillah	141.59	Dharwar	38.81
Mahableshwur	254.84	Ahmednuggur	21.83
Paunchgunnee	50.69	Shorapore	32.16
Sattarah	39.20	Madras	37.20

The mean monthly precipitation at Madras is as follows:

	°		°
January	1.33	July	3.20
February	0.28	August	5.24
March	0.36	September	4.76
April	0.63	October	10.09
May	1.03	November	12.43
June	2.03	December	3.25

The mean annual temperature of Bombay for the cotton year, from June to February, is 90°. The mean monthly temperature at Calcutta ranges from 66° in January to 85.7° in May. The winter mean is 67.3°; for spring it is 83.7°; for summer it is 82.5°, and for autumn it is 78.5°. One authority says "it is a remarkable fact in the cultivation of cotton in this country, where the plant lives from six to ten years, that the fiber produced is very inferior to that produced in the United States, and yet the seed from India that have been planted in the Southern States have invariably produced much more superior grades of cotton than that secured from similar seed in India. On the other hand, seed carried from the United States to India invariably deteriorated. This would indicate that the climate of the South has much to do with the improved character of the fiber that makes it the finest cotton of any produced in the world." The annual rainfall at Calcutta is 64.00 inches, but, as the above table shows, the seasons of rain are quite variable in India. The hot period in this country of India is from March to May, and during this time the temperature often goes as high as 100° to 110°, accompanied with tremendous thunderstorms.

MEXICO.

The area in which cotton is found in this country is quite limited, but the plant grows wild and is apparently native to the country. At Vera Cruz the mean annual temperature is 77°, while the range of temperature between the hottest and coldest months is only 12.4°.

The following gives the mean temperature for each month in the year:

	°		°
January	70. 0	July	81. 5
February	71. 6	August	82. 4
March	73. 4	September	81. 0
April	72. 2	October	78. 4
May	80. 5	November	75. 4
June	81. 9	December	71. 1

AUSTRALIA.

The cotton is also indigenous to this country and the fiber is generally picked from the same plant for five years. The frosts that occur are usually so light the cotton is not killed and the plant continues to grow from year to year. The seeds are planted in September and the picking begins in February and continues until June. The temperature during the cotton months ranges from 60° to 100°. The mean annual temperature at Sydney is 62.4°; at Victoria it is 56.8°, the lowest being 27° and the highest 111°. The character of fiber produced is coarse and not of that fine texture and length found in the United States. The rainfall at Melbourne is only 25.66 inches.

BRAZIL.

The best samples of cotton in this country come from Pernambuco. The climate in some respects is well adapted to the cultivation of cotton. The plant bears fruit throughout the year. Planting takes place in November and the first flowers open in June, and the flowering continues freely throughout the entire year. The temperature ranges from 24° to 104°.

Mr. O. H. Dockery, consul-general of the United States at Rio de Janeiro, in a report made to his Government gives the following interesting account concerning the climate of Brazil:

> The mean temperature in the country between Rio de Janeiro and the Amazon is 78.8° above zero; that of the Amazon is 80.6°. In no part of Brazil is it hardly ever higher than 96.8°.

Count du Chaillou states as follows concerning the temperature of this country:

> At the city of Rio de Janeiro, which is situated on the boundary line of the torrid and temperate zones, the average temperature, according to the Annuario do Imperial Observatorio for 1887, is 74.1° F., according to thirty-six years of observations. Only two seasons are known here, summer, or the rainy season, which lasts from October to the end of March, and winter, or the dry season, which lasts from April to September. The average temperature of summer is about 78.8°, and that of winter 69.8°. The highest temperature noted was 99.5°, and the lowest 50.3°, which is about the average temperature of Paris. The difference in the winter and summer temperature is, therefore, very slight in reality, but the long continuance of the heat and the warm nights make the heat keenly felt.

The following extracts were taken from a work prepared by the Brazilian Government for the Paris Exposition:

> During all the dry season the prairies, which serve as pasturage for the immense herds of cattle which are to-day one of the chief sources of provincial wealth, are completely dried and burned up by the sun. The live stock, whose weak and lean condition renders them pitiful objects, retire into wooded districts and subsist as best they may upon half dried leaves till the return of the rainy season. Vast tracts which then seemed calcined and sterile are in a few weeks covered with a luxuriant vegetation, and in a short time the cattle become fat and vigorous. But unfortunately it quite frequently happens that the rainy season, instead of following the dry, does not come for a whole year or several years. The subtropical region may be divided with relation to its rainfall into two distinct parts. * * * The first includes Alagoas, Sergipe, the coast of Bahia, and we will add Pernambuco. That part receives a rainfall every year, but the largest quantity occurs in June, July, and August. The southern part of Bahia, the provinces of Espirito Santo, Rio de Janeiro, a part of the coast of São Paulo, and the eastern part of Minas Geraes constitute the remainder of the subtropical zone. This subdivision is characterized by a predominance of rain, especially during the autumn and summer; that is from December to April. * * * The south of the province of São Paulo, the provinces Paraná, Santa Catharina, and Rio Grande do Sul constitute the third large division of Brazil. The temperature is very mild here, the average being below 68°, and the climate one of the finest in the world. * * * The rainy season is unlike that of any other region of the empire. In proportion as one leaves the equator the change from the dry to the wet season becomes less marked, while the breadth of variation in the temperature during the different months increases constantly.

The following tables are taken from the same work, and they give meteorological data at stations located near the equator to a point as far south as 32°:

TABLE III.—*Meteorological data, Brazil.*

Stations.	Latitude.		Altitude.	Temperature.			Annual rainfall.
				Mean annual.	Max.	Min.	
	°	′	*Feet.*	°	°	°	*Inches.*
Maranhão, Maranhão	1	27	142	81.32	92.84	69.98	90.65
Fortaleza, Ceará	3	44	....	79.88	....	....	59.00
Quixeramobim, Ceará	5	16	....	84.74	92.48	76.64	....
Amarante, Paranhyba	6	13	....	80.78	95.90	64.40	6.30
Recife, Pernambuco	8	04	10	79.16	99.14	61.34	....
Colonia da Victoria, Pernambuco	8	09	528	77.18	102.20	52.88	....
Colonia Isabel, Pernambuco	8	45	751	74.66	95.90	52.70	....
São Bento das Lages, Bahia	12	37	98	76.64	95.00	....	80.83
Bahia, Bahia	12	58	210	78.80	88.70	35.78	85.16
Queluz de Minas, Espirito Santo	20	40	....	67.82	90.32	33.80	57.52
Ribeirão Preto, Espirito Santo	21	10	1,706	68.00	93.20	32.00	23.62
Cascata, Rio de Janeiro	21	53	4,167	64.40	104.00	32.00	51.18
Nova-Friburgo, Rio de Janeiro	22	19	2,874	62.96	84.20	33.80	51.73
Rio de Janeiro, Rio de Janeiro	22	54	217	74.30	99.50	50.36	44.33
Santa Cruz, Rio de Janeiro	22	56	85	71.96	97.88	66.56	184.33
São Paulo, São Paulo	23	33	2,395	62.24	91.58	30.38	59.00
Coritiva, São Paulo	25	27	2,953	64.22	100.40	24.08	....
Colonia Nova-Petropolis, São Paulo	26	48	....	66.38	....	42.62	....
Colonia Blumenau, Paraná	26	55	....	70.52	....	....	60.71
S. Antonio de Palmeira, Paraná	27	54	1,896	64.40	93.20	30.20	....
Passo-Fundo, Santa Catharina	28	28	2,060	62.78	93.92	32.00	....
Taquara, Rio Grande do Sul	29	40	....	65.66	....	....	....
Santa Cruz, Rio Grande do Sul	29	45	....	66.56	95.00	....	....
Pelotas, Rio Grande do Sul	31	46	6,152	62.96	99.50	31.10	41.97
Rio Grande do Sul	32	00	52	65.84	90.32	33.80	35.91

TABLE IV.—*Rainfall at certain points in the interior of Brazil. published by authority of the Brazilian Government.*

Stations.	Summer. (Winter.)	Autumn. (Spring.)	Winter. (Summer.)	Spring. (Autumn.)	Total for year.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Valley of the upper Paranhyba	16.10	46.60	0.00	7.30	38.00
Sarbará	35.80	11.00	1.50	16.10	64.40
Congo-Soco	59.60	18.60	4.30	32.90	115.40
Itaibra do Campo	28.90	8.80	0.00	13.60	51.30
Queluz	37.20	6.10	2.10	11.80	57.20
Casa Branca	....	....	....	....	39.40
Height of Cubitão	50.40	37.70	24.40	28.30	140.80

ARGENTINE REPUBLIC.

Cotton grows in this country both as an annual and a perennial, and the culture is increasing each year. The following meteorological data have been extracted from the U. S. Agricultural Department's Miscellaneous Series, Report No. 2, by Almont Barnes, LL. B.:

> The mean annual temperature of the Argentine Republic is about the same as that of the United States; that is to say, that both countries are included within the limits of similar isothermal lines, from 70 to about 40 in the latter country, exclusive of the Florida peninsula, and also from 70 to about 40 in the former. The average range of the thermometer is therefore about the same. Both are situated geographically and as to range of climate within so-called temperate zones, and other things being equal the character and range of productions of the two would be the same.
>
> As in the case of other South American countries, the meteorological statistics of the Argentine Republic are few, fragmentary, and not representative of large regions. Premising that nearly the whole length of the coast of the country is swept or approached by the warm Brazilian ocean current, a branch of the great equatorial one, and that the estuary of the Rio de la Plata is constantly filled with water drawn in large bodies from

the tropics, both of which are modifying influences as to temperature and humidity, such classified and tabulated facts as are to be had and seem of value are presented in the following tables. The first tables relate to isolated stations, more or less representative of surrounding districts or provinces of the middle portion of the country relative to north and south, and of the entire breadth of that area east of the Andes.

They are taken from Dr. Burmeister's work, wherein the temperature is given according to the Réaumur scale, and the rainfall in millimeters, and reduced for use herein to Fahrenheit standard and to inches, respectively:

TABLE V.—*Maximum and minimum temperature at Buenos Ayres and monthly averages of the same for the four years ending with August,* 1878.

Months.	Maximum.					Minimum.				
	1870.	1871.	1872.	1873.	Average.	1870.	1871.	1872.	1873.	Average.
	°	°	°	°	°	°	°	°	°	°
September	81.05	71.38	74.75	74.75	75.43	39.43	38.75	34.25	38.75	37.75
October	74.75	78.80	74.75	82.63	77.68	43.25	43.25	41.00	46.63	43.48
November	88.25	86.90	78.80	86.00	85.10	44.83	43.25	42.13	43.25	43.48
December	93.65	99.95	92.75	92.30	94.78	53.38	60.13	52.25	51.13	54.28
January	93.65	96.80	97.25	90.95	93.65	52.25	53.60	51.13	57.88	53.83
February	89.38	90.05	90.05	88.25	89.38	59.00	58.10	53.38	54.50	56.30
March	83.75	88.25	83.75	82.63	85.55	52.03	53.83	47.30	47.75	50.23
April	73.85	80.60	78.80	77.00	77.68	40.55	37.63	38.75	41.00	39.43
May	69.80	68.00	63.50	70.25	68.00	34.25	34.25	35.38	31.33	33.80
June	65.75	70.25	70.25	69.13	68.90	30.88	33.13	34.25	32.00	32.68
July	64.63	66.88	65.75	73.63	67.78	32.45	29.75	29.75	34.25	31.55
August	66.65	72.50	66.88	72.50	69.58	29.75	35.38	36.50	35.38	34.25
Average	......	......	......	......	79.46	......	......	......	......	42.59

TABLE VI.—*Mean monthly, seasonal, and annual temperature at Buenos Ayres, and mean for four years ending with August,* 1873.

Months and seasons.	1870.	1871.	1872.	1873.	Average monthly.
	°	°	°	°	°
September	57.43	54.06	52.03	57.20	55.18
October	58.55	60.80	59.90	65.98	61.31
November	64.63	57.43	63.73	66.88	63.28
Spring mean	60.20	57.43	58.55	63.35	59.88
December	71.38	75.43	71.60	71.83	72.56
January	73.40	74.98	74.30	76.33	74.78
February	75.43	74.53	71.38	72.28	73.40
Summer mean	73.40	74.98	72.43	73.48	73.58
March	70.48	70.03	65.30	68.00	68.45
April	61.03	59.00	63.73	60.58	61.08
May	55.85	54.28	51.80	54.28	54.05
Autumn mean	62.45	61.10	60.27	60.95	61.19
June	50.00	50.68	50.00	52.03	50.68
July	47.75	47.75	48.43	47.53	47.86
August	48.20	51.35	52.70	53.83	51.52
Winter mean	48.66	49.93	50.38	51.13	50.02
Average for the year	61.18	60.86	60.41	62.22	61.17

The tables substantially agree in giving the range of the temperature at Buenos Ayres as from about 48° to 100° during the producing seasons for farm products, with an annual mean of about 76° during those months. The prevailing temperature may therefore be considered exceptionally good for crops suited to a temperate climate.

Monthly, seasonal, and annual rainfall, actual and mean, at Buenos

Ayres, for the eight years ending with 1868, taken by M. Eguia, and approved by Dr. Burmeister:

TABLE VII.—*Monthly, seasonal, and annual rainfall at Buenos Ayres.*

Month and season.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	Means.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
September	2.50	3.06	1.64	4.10	2.75	1.40	1.17	3.56	2.53
October	5.93	4.88	0.58	1.30	2.50	9.75	0.24	5.82	3.87
November	0.69	3.37	0.88	1.57	0.58	2.23	3.00	3.93	2.03
Spring	9.12	11.31	3.11	6.97	5.83	13.38	4.41	13.31	8.43
December	4.64	6.04	3.60	2.39	1.59	3.19	3.75	6.41	3.95
January	0.45	0.51	4.25	1.42	2.05	0.56	0.41	2.53	1.52
February	1.22	4.04	3.89	1.95	0.29	1.98	1.31	6.91	2.70
Summer	6.31	10.59	11.74	5.76	3.93	5.72	5.47	15.85	8.17
March	1.20	2.69	2.83	3.35	0.98	1.24	1.51	4.28	2.26
April	2.87	1.94	0.49	3.82	4.25	2.98	4.88	1.79	2.88
May	0.12	5.67	3.92	3.16	2.82	5.19	1.18	*3.01	3.01
Autumn	4.19	10.29	6.24	10.33	8.05	9.41	7.57	9.08	8.14
June	0.70	4.88	2.92	3.00	4.53	2.93	2.75	3.37	3.14
July	0.48	2.92	0.99	1.45	2.47	6.22	2.74	0.21	2.19
August	2.19	1.26	2.61	1.74	2.51	2.13	0.35	3.16	1.99
Winter	3.37	9.06	6.52	6.19	9.50	11.28	5.85	6.74	7.32
The year	22.99	41.25	27.62	29.26	27.31	39.80	23.29	44.97	32.06

*Amount not given in this single instance, and therefore the average amount is assumed for it.

EGYPT.

Upper Egypt is almost entirely rainless, while Lower Egypt has a small rainfall. In Lower Egypt the mean temperature ranges from 80° to 90° in summer and from 50° to 60° in winter. In Upper Egypt the mean temperature in summer ranges from 90° to 100°, and from 60° to 70° in winter. Cotton is cultivated by artificial irrigation, and is mostly to be found in Lower Egypt, the upper country being too dry.

The following table gives, in an interesting manner, the general comparison between the several foreign countries considered in this paper and the cotton belt of the southern United States. The mean temperatures and annual precipitations are too general to bring out specific differences, but they will serve to show the striking contrasts between the several countries under consideration:

TABLE VIII.—*Comparative temperature and rainfall.*

Countries.	Temperature.			Annual precipitation.
	Mean annual.	Mean spring.	Mean summer.	
	°	°	°	*Inches.*
United States (cotton belt)	63.5	63.5	78.0	50.80
West Indies	79.5	78.9	78.5	63.00
British India	77.8	81.8	86.2	74.22
Mexico (Vera Cruz)	76.6	75.3	82.0	....
Australia (Sydney and Victoria)	59.6	....	....	....
Brazil (Rio Grande do Sul)	65.6	63.8	74.7	*72.36
Argentine Republic (Buenos Ayres)	61.2	69.9	73.6	32.06
Egypt, Lower (Alexandria)	....	....	76.6	7.51

* Entire country.

NOTE.—The mean temperature of the portion of Brazil between Rio de Janeiro and the Amazon is 78.8°. That of the Amazon is 80.6°; and the summer temperature (winter) of Pernambuco is 79.5°, while the winter (summer) temperature is 76.8°. A large portion of the cotton of Brazil is grown in Pernambuco.

III.—THE GENERAL CLIMATIC FEATURES PREVAILING IN THE SOUTHERN UNITED STATES DURING THE PREPARATION OF THE LAND FOR THE PLANTING OF THE SEED.

The winters of the South are seldom severe, and the temperature rarely reaches zero except in the more northern latitudes of the cotton region, and not often even there. It is a well recognized fact among cotton planters that those portions of the country where the changes of temperature are sudden and the fall reaches zero during every winter and sometimes frequently during the same winter, will permit of too short a period between frosts to enable the cotton plant to perfect its growth and mature its fruit. Many efforts have been made to force the plant to produce fiber in the northern portions of Kentucky and the colder regions in west and northwest Texas, but all such efforts have proved total failures, even though the general conditions of the soil in those sections of the country are of a nature well suited for the cultivation of cotton.

The following table of winter temperatures at those stations in the cotton region giving continuous records for ten years or more, is given to bring out the above conclusions in regard to the growth of cotton. A careful comparison of this table with the outline map, Chart VII, will show that wherever the altitude or latitude causes the temperature to range low during the winter and spring months the cultivation of cotton is correspondingly reduced to a minimum:

TABLE IX.—*Winter minimum temperatures at stations of the cotton belt of the Southern States.*

Stations.	Length of record.	Minimum.	Month and year.	Mean minimum.			No. of times min. was down to zero and below.
				December.	January.	February.	
Northern portion.	*Years*	°		°	°	°	
Atlanta, Ga	13	— 2	Jan., 1886	37·6	35·4	39·7	2
Charlotte, N. C	13	— 5	Dec., 1880	35·5	33·8	37·4	2
Chattanooga, Tenn	13	— 7	Jan., 1886	35·6	34·0	37·7	2
El Paso, Tex	14	— 5	Dec., 1880	32·9	30·7	35·8	2
Fort Davis, Tex	11	— 3	Jan., 1886	33 2	30·1	34·8	2
Fort Elliott, Tex	10	—14	Jan., 1888	25·6	18·7	24·2	12
Fort Smith, Ark	10	— 7	Jan., 1886	33·8	26·8	32·3	3
Knoxville, Tenn	21	—16	Jan., 1884	32·3	30·6	34·2	7
Little Rock, Ark	13	— 5	Jan., 1886	38·5	33·7	38·0	1
Memphis, Tenn	20	— 8	Jan., 1886	38·1	32·8	37·7	2
Nashville, Tenn	21	—10	Jan., 1884	33·9	30·5	34·1	9
Middle portion.							
Auburn, Ala	14	3	Jan., 1884	39·7	38·2	44·8	0
Augusta, Ga	20	6	Jan., 1886	39·0	38·8	42·0	0
Charleston, S. C	20	10	Jan., 1886	44·8	44·5	46·2	0
Green Springs, Ala	27	2	Jan., 1886	....	....	....	0
Hatteras, N. C	17	8	Dec., 1880	42·0	39·3	41·9	0
Kittyhawk, N. C	17	5	Feb., 1886	40·1	36·6	39·4	0
Montgomery, Ala	19	5	Jan., 1886	40·6	40·1	44·4	0
Palestine, Tex	10	0	Jan., 1886	42·6	38·3	43·8	1
Shreveport, La	20	1	Jan., 1886	41·6	38·2	43·1	0
Union Springs, Ala	24	8	Jan., 1886	....	....	....	0
Vicksburg, Miss	20	3	Jan., 1886	42·7	39·9	44·2	0
Wilmington, N. C	21	9	Jan., 1884	39·9	38·9	41·5	0

TABLE IX.—*Winter minimum temperatures, &c.*—Continued.

Stations.	Length of record.	Minimum.	Month and year.	Mean minimum.			No. of times min. was down to zero and below.
				December.	January.	February.	
Southern portion.	*Years*	°		°	°	°	
Brownsville, Tex	16	18	Dec., 1880 Jan., 1881	53.5	50.0	55.2	0
Cedar Keys, Fla	10	15.5	Jan., 1886	51.4	51.0	54.9	0
Galveston, Tex	21	11	Jan., 1886	51.5	47.4	52.9	0
Indianola, Tex	14	12	Jan., 1886	50.1	43.8	49.9	0
Jacksonville, Fla	20	15	Jan., 1886	49.1	47.5	50.8	0
Mobile, Ala	21	11	Jan., 1886	44.4	43.6	47.6	0
New Orleans, La	21	15	Jan., 1886	48.7	47.3	51.2	0
Pensacola, Fla	12	15	Jan., 1886	47.3	46.3	51.0	0
Rio Grande City, Tex	15	19	Jan., 1881	50.5	47.7	54.2	0
San Antonio, Tex	15	6	Jan., 1886	45.2	41.0	46.8	0
Savannah, Ga	21	12	Jan., 1886	44.4	43.7	46.9	0

The records from which these results have been secured cover periods from ten to twenty-one years.

For convenience of reference and comparison I have divided the region under discussion into three distinct portions, viz., northern, middle, and southern sections of the cotton belt. The lines separating these divisions are irregular and will more nearly coincide with the normal lines of mean minima temperatures than with the lines of latitude. In arranging the stations under this classification I have been governed largely by the mean minima temperatures recorded by the respective observers; but to correctly express the severity of the climate in winter it is best also to consider the lowest possible range of temperature. With this interpretation, therefore, I have placed Atlanta, Ga., Little Rock, Ark., and Memphis, Tenn., in the northern division, although the mean minima would warrant placing them in the middle section. When the question of the growth of cotton is considered, however, it will be noticed that the conditions of climate and soil are amply propitious for all demands of the plant in the country surrounding these three cities.

Those sections in Texas placed in the northern division, that are situated far south geographically, give greater depressions of temperature than those in the east not so far south. This is largely due, no doubt, to the greater altitude, in some instances, of these western stations, and also because of the blizzards that sweep across portions of Texas each year. At the following stations where the minimum temperature goes so low and so frequently during the winter, there is very little, if any, cotton planted; and in the neighboring country where the cultivation has been attempted results have been very discouraging, viz., El Paso, Fort Elliott, Fort Smith, Knoxville, and Nashville. In the case of Nashville, however, there is a section of country just south of the city that produces very large yields of cotton in favorable years. It will thus be noticed that although some of the stations occupy positions quite far north local causes may so modify the climatic conditions as to permit the successful cultivation of cotton in the immediate neighborhood.

The months of February and March are spent by the planters in preparing the land for the planting of the seed, and the season is very well adapted for such work. The weather is never severe enough to prevent outdoor work, and the ground is never so hard frozen as to impede the progress of the plow.

In the lower half of the Southern States the fall of snow is very unusual, and even in the more northern limits it scarcely covers the ground above a few inches and remains only a few days at the most. It is possible, therefore, under these conditions, for the farmers to work almost continually during the winter months. The lands are generally plowed broadcast in the winter so that the rains and the frosts may disintegrate the soil and render the ingredients available to the demands of the plants. The plowing usually begins about the 1st of February and continues until planting of the seed in April or May, depending, of course, upon the locality of the place. In winter the rains are frequent and the soil is often soaked. The freezing of this water at night and quick thawing under the influence of the noonday sun cause great changes to take place in the chemical and physical conditions of the soil.

IV.—THE CLIMATE OF THE SEED-PLANTING SEASON.

The heavy frosts in the South have generally ended by the 15th of April, and there is little danger of the young cotton plant becoming killed if it is planted so as to germinate about the 1st of May. It is customary, therefore, to put the seed in the ground from April 1 to May 10, the time depending largely upon the locality in the cotton belt. With the exception of the extreme south the cotton that is planted before the 15th of April is apt to become reduced in its vitality by cool nights that prevail during the first half of April. In most sections of the cotton belt light frosts, with occasional killing frosts, frequently retard the growth of vegetation during the first weeks of April, particularly in the northern limits of the region. It is therefore customary in those portions of the belt to delay the planting until the first week in May so as to escape this period of cool weather. To bring out this fact the following table of the times of killing frosts in the spring is given:

TABLE X.—*Dates of last killing frosts in the cotton belt, exhibiting early and backward springs, from* 1871 *to* 1891, *inclusive.*

ALONG THE NORTHERN LIMIT.

Stations.	Earliest.	Latest.	Average.
Atlanta, Ga	February 2, 1882	April 8, 1886	March 17.
Charlotte, N. C	March 10, 1884	May 3, 1879	March 30.
Chattanooga, Tenn	January 25, 1880	April 8, 1886	March 18.
El Paso, Tex	March 7, 1885	April 22, 1882	March 31.
Fort Davis, Tex	February 25, 1888	April 22, 1884	April 1.
Fort Elliott, Tex	March 2, 1890	April 30, 1880	April 6.
Fort Smith, Ark	March 9, 1884	April 5, 1887	March 22.
Knoxville, Tenn	March 17, 1890	April 25, 1883	April 7.
Little Rock, Ark	February 22, 1882	April 14, 1881	March 21.
Memphis, Tenn	February 25, 1889	April 16, 1882	March 31.
Nashville, Tenn	February 2, 1882	May 1, 1886	March 28.

THROUGH THE MIDDLE PORTION.

Auburn, Ala	March 11, 1889	April 6, 1886	March 23.
Augusta, Ga	February 6, 1882	April 14, 1885	March 18.
Charleston, S. C	January 4, 1882	April 2, 1881, 1887	February 25.
Hatteras, N. C	January 4, 1882	April 5, 1881	February 23.
Kittyhawk, N. C	January 18, 1878	April 19, 1875	March 12.
Montgomery, Ala	February 2, 1882	April 6, 1886	March 8.
Palestine, Tex	February 24, 1889	April 7, 1886	March 17.
Shreveport, La	January 12, 1887	April 7, 1886	February 24.
Vicksburg, Miss	January 16, 1874	April 6, 1886	February 27.
Wilmington, N. C	January 23, 1882	April 20, 1890	March 14.

ALONG THE SOUTHERN LIMIT.

Brownsville, Tex	December 26, 1880	March 1, 1890	January 29.
Cedar Keys, Fla	December 7, 1887	March 12, 1888	January 22.
Galveston, Tex	December 26, 1880	March 1, 1890	January 27.
Indianola, Tex	November 30, 1878	April 14, 1881	February 7.
Jacksonville, Fla	December 18, 1880	March 23, 1883	February 3.
Mobile, Ala	December 27, 1880	April 6, 1886	February 21.
New Orleans, La	November 26, 1882	March 14, 1886	January 13.
Pensacola, Fla	December 27, 1880	March 23, 1881, 1885	February 24.
Rio Grande City, Tex	December 16, 1882	March 2, 1890	January 24.
San Antonio, Tex	December 7, 1878	April 14, 1881	February 11.
Savannah, Ga	January 4, 1882	April 13, 1885	February 26.

April is a month of showers, and for this reason it is peculiarly well adapted for planting. These rains are not usually heavy, but occur at frequent intervals so as to keep the soil in that moist condition best suited to germinate the seed. It is a fact well known among scientists that if the soil becomes too heavily charged with water while the seed is undergoing the stage of transformation prior to germination decay frequently sets in, and on the other hand, if the soil is very dry, rendered so by the absence of rain or under the influence of drying winds, the seed cannot obtain enough moisture to start the growth and replanting becomes necessary. Again, if the soil contains a sufficiency of moisture for the growing plant, and the nights in early April are cool, the rapid evaporation from the leaf surface under the action of the winds may reduce the temperature so low as to seriously damage the organic structure of the tender vegetable. When chilling winds and not solar heat are the agents at work creating the circulation of moisture in the plant and reducing the amount of surplus water in the tissue, the young life is greatly endangered and the vegetable organization is frequently disarranged or ruptured. It is the part of wisdom, therefore, obtained through long experience, that induces the cotton planter to delay putting in the seed until the latter part of April or first part of May, when the soil becomes warmed under the influence of the spring sun, and the number of cool days are reduced to the minimum.

The seasons of rain are so distributed throughout the spring months as to keep the atmosphere and soil in a condition generally suited for the full development of the young plant, and that causes the roots to take a deep hold of the soil and the tap root of the subsoil preparatory to contending against the droughts of summer. A very wet spring will cause the plant to form numerous surface roots, to the great sacrifice of the tap root and those that tend downward. Under these conditions the dry season that usually prevails during the summer months will soon cause the plant to wither and shed its "squares," because of the dry condition of the surface soil in which it is forced to live, and in which it must secure the moisture required for its growth. But if, on the other hand, the month of May is comparatively dry, with occasional showers interspersed throughout the month, the tap and lateral roots take deep hold of the soil and the subsoil, so that sufficient moisture is brought up from below to sustain the vitality of the plant during the fiber-forming period when plenty of sunshine and dry weather prevail. In this connection it will be interesting to note the following extract from Professor Johnson's work, "How Crops Feed," that shows in a striking manner how beneficial dews and frequent light showers during the growing period will become to the plant, and what great damage must result if our springs were seasons of continued rain, as is so common in many tropical regions of the world:

> Let us suppose dew or rain to have saturated the ground with moisture for some depth. On recurrence of a dry atmosphere, with sunshine and wind, the surface of the soil rapidly dries; but as each particle of earth escapes (by evaporation) into the atmosphere, its place is supplied (by capillarity) from the stores below. The ascending water brings along with it the soluble matters of the soil, and thus the roots of the plants are saturated in a stream of their appropriate food. The movement proceeds in this way so long as the surface is drier than the deeper soil. When by rain or otherwise the surface is saturated—it is like letting a thin stream of oil run upon the apex of the lamp-wick—no more evaporation into the air can occur, and consequently there is no longer any ascent of water; on the contrary, the water by its own weight penetrates the soil, and if the underlying ground be not saturated with moisture, as can happen where the subterranean fountains yield a meager supply, then capillarity will aid gravity in its downward distribution. * * * It is easy to see how, in a good soil, capillarity thus acts in keeping the roots of plants constantly immersed in a stream of water or moisture that is now ascending, now descending, but never at rest, and how the food of the plants is thus made to circulate around the organs fitted for absorbing it. * * * Thorough drainage, by loosening the soil and causing a rapid removal from below of the surplus water, has a most decided influence, especially in springtime, in warming the soil and bringing it into a suitable condition for the support of vegetation.

TABLE XI.—*Average rainfall, average number of rainy days, and average number of clear days for the month of May for the years 1871 to 1891. These averages were obtained from data furnished by all regular stations throughout the cotton belt.*

Years.	Northern cotton belt.			Middle cotton belt.			Southern cotton belt.		
	Rainfall (in inches).	No. of rainy days.	No. of clear days.*	Rainfall (in inches).	No. of rainy days.	No. of clear days.*	Rainfall (in inches).	No. of rainy days.	No. of clear days).*
1871	4.66	12	8	6.12	8	16	4.30	9	9
1872	3.62	10	11	7.78	10	12	2.78	6	10
1873	5.56	12	4	7.63	12	8	8.86	13	7
1874	1.06	6	13	2.97	7	14	2.94	6	13
1875	2.97	12	10	2.79	7	11	3.20	7	12
1876	5.94	10	9	5.24	10	9	3.00	6	12
1877	1.53	6	14	3.00	6	15	1.67	6	11
1878	3.00	11	11	5.07	9	12	4.37	9	9
1879	3.52	8	13	3.54	10	13	3.00	6	14
1880	4.22	8	13	3.66	9	14	4.86	10	10
1881	3.34	11	10	2.57	8	10	2.40	7	11
1882	5.89	11	10	3.80	8	8	4.40	8	8
1883	3.34	7	15	3.66	6	11	4.32	7	11
1884	5.20	11	11	6.29	8	9	5.24	10	12
1885	4.35	12	11	6.57	12	8	5.40	11	7
1886	2.83	7	13	2.88	6	16	2.08	4	15
1887	3.68	12	11	4.06	11	10	3.90	9	10
1888	3.92	12	10	5.27	11	8	4.54	10	10
1889	2.51	7	15	2.66	6	15	1.08	4	15
1890	4.05	13	14	5.76	10	12	4.24	10	12
1891	2.67	6	13	2.85	6	13	1.92	4	13
Mean	3.71	10	11	4.48	9	12	3.74	8	11

* No estimate is made in these columns for the sunny weather that occurred during what are technically termed "fair days," but the averages represent only those days that have furnished less than one per cent. of cloudiness.

It will be seen from the accompanying table that May is comparatively a dry month—just enough rain falling to enable the plant to grow well and not enough to cause too rapid development of "weed." It is a trite saying among farmers of the South that "a dry May produces a clean crop." This peculiar climatic condition that generally prevails in the cotton region during the month of May, may, in a large measure, enable the farmer to clean his crop, but the equally important fact of deep root penetration, already referred to, must not be overlooked.

In studying the climatology of any section of country, to determine its adaptability to the growth of certain kinds of plants, it is not well to draw definite conclusions alone from annual precipitations, nor even from the amounts that fall in each season; although these results are very important and should be carefully considered in their proper connections. But when we remember what great changes take place in the condition of the plant within thirty days, valuable conclusions may be drawn by comparing the month of one year with that of another. In this connection the following questions may be appropriately asked: When does the rain fall in largest amounts; in spring, summer, autumn, or winter? Is there a dry season and a wet season? But the answers to these questions alone will not bring out all the special points of advantage or disadvantage in studying the adaptation of any section of the country to the special cultivation of certain kinds of plants. The cotton is a peculiar plant in respect to its demands for moisture, and one month's time in the middle of spring may decide its fate for or against producing a good yield of lint. Experience has taught that the rains must be distributed during the spring and early portion of summer while the plant is young and while it is in its blooming state, so as to keep the soil in the condition best suited to yield up its food elements to the rapid demands of the growing limbs, leaves, and buds; but at the same time there must be ample sunshine, because the cotton plant loves the sunlight. The fact must not be lost sight of either, as has been previously stated, that the soil must not be so moist for any length of time during April and May as to cause too rapid multiplication of surface roots. The depth of the soil controls, to a large degree, the quantity of moisture that will be retained in it after a season of rains, and it is therefore of great importance that the land should be deeply broken and well pulverized during the preparatory season in February and March; and after the plant is up above the soil the surface should not be allowed to harden and bake into a crust but should be often stirred. The pulverization of the soil will enable the small particles of earth to take up the moisture floating through the atmosphere during the night and early morning and thus add a new and steady supply for the roots to absorb. Circulation is absolutely necessary for good results. An excess of water prevents that due admixture and division of the ingredients so important for the healthy growth of the plants. It also diminishes the fertilizing properties of the manures that may be added to the soil when the seed are planted. The excess of water also lowers the temperature of the soil, and it prevents free circulation of air so necessary for the healthy condition of the roots. The cotton plant is particularly averse to excessive rains and a saturated atmosphere and soil, and will not thrive well under such conditions. Whenever these conditions prevail during the spring or the growing season the powers of the plant to produce an abundance of well-matured fiber will be greatly curtailed.

The cotton plant loves the sun, and during its entire life must have an extra quantity of warm rays. It thrives best in that climate where the atmosphere is well warmed by the almost vertical rays of the sun. In discussing the temperature phase of this subject this fact must be well borne in mind. Observation extended over a wide field of experience has proven this proposition to be indisputable. Seven months from the planting of the seeds until picking is about completed are required for the full and satisfactory development of the cotton in all its functions. These seven months must contain a large share of sunshine and be free from heavy frosts. Table XXV, at the end of this work, will show that the percentage of cloudy days is small when compared with the amount of clear weather. From this table we learn that on an average, in the middle section of the cotton belt, 46 days out of 100 produce cloudy weather, while 54 days are entirely clear. This table also shows that 32 days in 100 throughout the middle portions of the belt are likely to produce rain during the spring of the year.

Table XII, minimum temperatures, page 34, proves that during the months of April and May the weather is seldom so cold as to entirely destroy the tender cotton plant just after it reaches the surface of the ground when it is most susceptible to the influence of cold. As has already been stated, the seed is planted about the middle of April in the southern portions of the belt, and the plant comes above the surface some time during the first part of May. The table herewith given proves that very rarely does the thermometer record temperatures lower than 33°. The maximum temperature sometimes goes as high as 98°, but the range is generally between 80° and 95°, thus supplying a large percentage of heat rays for the warmth of the soil. As far south as Mobile, during a period of 21 years, the temperature ranged above 40° as often as 18 years and above 45° as often as 10 years. At Augusta, Ga., in the middle area of the cotton belt, the minimum temperature, throughout a period of 19 years, ranged above 40° nine times, and fell below 35° only five times during the period covered by the records. At Vicksburg, also in the middle section, the minimum temperature, in a period of 19 years, ranged above 40° fifteen times, and fell below 35° only twice. At Montgomery, Ala., in the central belt, and on the edge of the great prairie region, the minimum temperature ranged above 40° 13 years out of a record of 19 years. These facts indicate a remarkably fair season for the planting of the seed, and show that the soil is not so chilled as to prevent the rapid germination of the plant. It is therefore customary among the farmers throughout the extent of this southern area to plant a week, and in some places two weeks, earlier than in that portion of the cotton belt located north of Montgomery and Augusta.

By the first of May cotton planting has become general throughout the entire area of the cotton belt. After the close of the second week in May frost is not likely to occur, and, although there may be a few cool nights, the cotton plant in its young, tender condition, stands a very fair chance in all sections of the country under consideration. By a glance at the table of temperatures for May we will see that the mean minimum ranges above 52° at all stations, and at the majority it is above 60°. The minimum temperature, even at the extreme northern stations, never falls below 35°, and at twenty-five out of thirty-one stations furnishing continuous records, the minimum is never lower than 40°.

At Memphis, Tenn., one of the stations situated in the northern limits of the cotton region, and around which cotton is quite successfully cultivated, the minimum temperature during a period of twenty years ranged above 45° fifteen years, and did not fall below 40° a single time during those twenty years. When we couple with this fact the frequency with which the thermometer recorded temperatures above 90° (thirteen times) during this long period, we can readily understand why it is safe to put in the crop even as early as the last week in April. This is not true with regard to the section of country immediately surrounding Knoxville, Tenn., another one of the northern section stations. On account of the difference in altitude between Memphis and Knoxville, although there is so little in latitude, the climate of the latter place is more severe in May than at the former, and consequently the season is so much shortened the growth of the cotton there is not so certain. At Knoxville the minimum temperature, in a period of twenty-one years, fell too near the frost limits eleven out of the twenty-one years, and of the remaining years only five gave minimum results above 45°.

Table XIII, page 36, giving by comparison the minima and the mean minima temperatures, will be interesting in this connection. The latter represents what I have termed plant temperatures, because they are apt to occur each year, while the minima may not occur oftener than once in several years. I have selected for this table four stations in the northern part of the cotton belt, five in the central portion, and four in the southern section. These stations are so distributed as to give average results for the entire belt. It will be noticed that where the mean minimum temperature is below 55° the growth of cotton is not entirely successful, while in those portions of the region where cotton is cultivated on a large scale the mean minimum temperature ranges from 55° to 65° in April. This table, to bring out its most important features, should be compared with the map of the cotton area, Chart VII, and also compared with the table of last frosts furnished elsewhere. The first figures represent the minima temperatures and the second figures are given for the mean minima temperatures:

TABLE XII.—*Temperature for April and May at stations in the cotton region.*

NORTHERN SECTION.

Stations.	Monthly mean.		Mean max.		Mean min.		Maximum.				Minimum.				April.		May.	
							April.		May.		April.		May.					
	April.	May.	April.	May.	April.	May.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year	Range between max. and min.	Range between mean max. and mean min.	Range between max. and min.	Range between mean max. and mean min.
	°	°	°	°	°	°									°	°	°	°
Atlanta, Ga	61.6	68.9	71.0	78.3	52.2	59.6	88	1887	91	1879, '81	25	1881	57	1889, '91	63	18.8	34	18.7
Charlotte, N. C	59.9	68.8	70.4	78.9	49.4	58.7	91	1888	95	1889	28	1881	38	1889, '91	63	21.0	57	20.2
Chattanooga, Tenn	62.7	68.9	74.2	79.6	52.2	58.2	89	1889, '91	93	1879	25	1881	40	1888, '89	64	23.0	53	21.4
El Paso, Tex	64.3	73.1	80.1	88.9	48.4	57.3	98	1879	105	1885	29	1882	39.5	1884	69	31.7	65.5	31.6
Fort Davis, Tex	60.7	68.4	75.1	82.9	46.3	54.0	95	1879	101	1881	25	1882	40	1880, '84	70	28.8	61	28.9
Fort Elliott, Tex	57.1	69.7	70.9	77.3	43.4	52.1	96	1880	98	1889	20	1881, '86	35	1885, '89	76	27.5	63	25.2
Fort Smith, Ark	62.8	68.9	74.0	80.3	51.7	57.6	91	1887	98	1886	30	1886, '87	40	1889	61	22.3	58	22.7
Knoxville, Tenn	58.0	66.7	68.3	77.6	47.7	55.8	89	1887	94	1877	24	1875, '81	36	1888, '89	65	20.6	58	21.8
Little Rock, Ark	63.5	70.2	73.3	79.5	53.7	60.9	94	1880	93	1886	28	1886	44	1883, '85, '89	66	19.6	49	18.6
Memphis, Tenn	62.5	70.3	71.5	79.4	53.4	61.1	88	1882, '83	96	1879	27	1881	41	1883, '85	61	18.1	55	18.3
Nashville, Tenn	59.6	67.9	69.5	78.2	49.7	57.5	90	1872	93	1879	26	1875	37	1877, '88, '90	64	19.8	56	20.7
Means	61.0	69.2	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

MIDDLE SECTION.

Stations.	Monthly mean.		Mean max.		Mean min.		Maximum.				Minimum.				April.		May.	
	April.	May.	April.	May.	April.	May.	April. Degrees.	April. Year.	May. Degrees.	May. Year.	April. Degrees.	April. Year.	May. Degrees.	May. Year	Range between max. and min.	Range between mean max. and mean min.	Range between max. and min.	Range between mean max. and mean min.
Auburn, Ala	63.4	71.4	72.7	80.9	54.0	61.9	86	1881	93	1881	27	1881	42	1890	59	18.2	51	19.0
Augusta, Ga	64.6	72.5	75.3	83.4	53.8	61.6	93	1885, '87	100	1878	29	1887	42	1877, '91	64	21.5	58	21.8
Charleston, S. C	64.4	72.3	71.9	79.5	56.9	65.1	88	1888, '90	96	1889	32	1881	47	1876	56	15.0	49	14.4
Hatteras, N. C	56.9	67.2	63.2	72.5	50.6	61.8	76	1885, '86, '87	88	1881	31	1875, '81	43	1876	45	12.6	45	10.7
Kittyhawk, N. C	56.0	65.9	62.7	72.9	49.3	58.9	92	1888	94	1889	29	1881	42	1876, '77	63	13.4	52	14.0
Montgomery, Ala	65.8	73.4	76.0	83.8	55.6	63.0	90	1880	98	1875	30	1881	44	1883, '89	60	20.4	54	20.8
Palestine, Tex	66.7	71.6	76.3	81.2	57.0	62.0	88	1887	92	1886, '87	36	1886, '91	46	1887, '91	52	19.3	46	19.2
Shreveport, La	67.3	74.0	77.4	84.0	57.3	64.0	96	1887	101	1875, '86	32	1881	47	1876, '77	64	20.1	54	20.0
Vicksburg, Miss	65.9	72.9	75.4	82.9	56.7	63.4	92	1887	95	1874, '77	31	1881	46	1877	61	18.7	49	19.5
Wilmington, N. C	60.5	67.2	69.3	76.6	51.7	57.7	90	1880	97	1889	28	1875	38	1876	62	17.6	59	18.9
Means	63.2	70.8	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

SOUTHERN SECTION.

Brownsville, Tex	74.4	79.3	82.4	86.2	66.5	72.3	98	1886	99	1877	43	1881	49	1877	55	15.9	50	13.9
Cedar Keys, Fla	69.8	75.5	76.1	81.9	63.4	69.0	88	1880	91	1880, '81	38	1881	50	1883	50	12.7	41	12.9
Galveston, Tex	70.0	70.1	75.1	81.5	64.9	70.7	85	1878	91	1875, '77	43	1886	54	1876	42	10.2	67	10.8
Jacksonville, Fla	68.9	72.0	78.0	83.6	59.7	60.4	91	1880	99	1878	34	1891	48	1877	57	18.3	51	23.2
Mobile, Ala	67.1	74.2	75.5	83.2	58.7	65.1	90	1881, '83	98	1878	32	1881, '91	46	1889	58	16.8	52	18.1
New Orleans, La	68.9	74.9	76.1	82.0	61.8	67.7	88	1889	92	1877	38	1881	53	1891	50	14.3	39	14.3
Pensacola, Fla	67.7	73.4	74.6	80.1	60.8	66.7	92	1887	93	1881	34	1881, '91	47	1883, '89	58	13.8	46	13.4
Rio Grande City, Tex	74.2	80.9	87.8	91.5	60.5	70.3	109	1878	112	1879	43	1881	49	1877	66	27.3	63	21.2
San Antonio, Tex	69.4	74.8	79.7	84.7	59.2	64.8	96	1886	104	1879	35	1886	46	1889	61	20.5	58	19.9
Savannah, Ga	66.6	73.2	74.7	81.4	57.4	65.1	89	1873, '87	98	1878	33	1881	48	1877	56	17.3	50	16.3
Means	69.7	75.4	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

TABLE XIII.—*Minima and mean minima temperatures at selected stations.*

Stations.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	Average.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Atlanta.....	30 50.2	36 55	25 50	43 56	37 52	35 50.2	36 51.5	32 51.8	36 50.3	40 54.1	34 51.8	42 53	28 52.6	34.9 52.2
Fort Smith.	....	....	....	....	37 51.2	35 48.9	40 52.2	30 49.5	30 50.3	42 55.4	43 54.1	39 53	28 50.6	36.0 51.7
Knoxville ..	25 44.8	30 49.5	24 44.7	36 51	33 58.4	31 45.7	29 46.9	29 49.5	29 46.3	36 49.5	32 48.6	35 50.7	29 49.3	30.6 48.8
Memphis...	36 51.4	39 53.4	27 50.6	41 56.5	39 54.4	41 51.8	35 55.1	34 53.2	38 53.7	43 55.8	41 54.4	39 53.4	33 54.9	37.4 53.7
Kittyhawk .	31 45.4	33 50.3	29 48.1	38 51.8	36 51.2	38 45.8	35 46.8	39 48.6	33 46.4	39 47	41 46.4	37 51.5	36 48.6	36.5 48.4
Charleston .	39 56	39 58.9	32 52.7	46 59.9	45 58.5	43 56.2	43 56.7	39 55.5	33 55.5	50 58.9	42 55.1	47 57.3	38 57.9	42.1 56.1
Montgomery	36 53.9	40 59.2	30 54	48 59.1	41 56.7	43 54.2	38 53.6	36 54.9	40 54.4	44 57.9	41 55.1	44 56.8	31 55.3	39.4 55.8
Palestine...	....	....	....	43 59	44 56.5	38 53.6	47 58.8	36 55.4	40 55.4	42 61.3	50 58.4	46 56.7	36 54.9	42.2 57.0
Vicksburg..	39 55.4	41 59.4	31 56.6	47 60.3	44 57.5	44 54.7	42 58.7	35 54.9	43 55.2	46 58.7	46 56.5	51 59	33 56.4	41.7 57.2
Brownsville	50 67	46 69.2	43 64.7	48 66.2	58 67.6	47 64.1	59 69	45 64.4	51 65.7	61 68.4	56 67.2	53 67.7	50 63.3	51.3 66.7
Jacksonville	39 57.5	42 62.6	37 58.4	56 64.2	52 64	47 60.6	47 59.9	44 59.2	38 58.2	49 61.9	44 57.3	47 60.4	34 58.2	44.3 60.2
Mobile	40 57.1	42 62	32 57.5	49 62.5	47 61.1	43 58.5	40 59.1	37 56.2	41 55.9	50 60.9	44 58	48 60.5	32 57.1	42.0 58.9
N. Orleans..	46 58.7	49 64.8	38 59.5	56 66.1	51 64.7	50 61	52 64.9	41 58.3	48 60.1	56 63.3	54 61.4	56 62.5	41 60.9	49.0 62.0

SOIL TEMPERATURES.

Soil temperatures furnish interesting data for comparison with air temperatures in the study of the subject of the climatology of plant growth. These temperatures show how much below the surface of the earth the heat of the sun has penetrated, and the power certain soils have for retaining the heat required for all the demands of the germinating seed. It is to be regretted that so little work has been done in this connection and that so little data can be secured relating to the temperature of the soil. The observations at Auburn and Uniontown, Ala., from which records Table XV has been made, cover so limited a period of time, the conclusions drawn in connection with the subject under consideration can only be general.

In the discussion of this portion of our subject it may not be amiss to make a comparison between what has been determined to be the germinating temperature of seeds and the general temperature conditions of the soil during the planting season of April and May. The seeds that have been selected for this purpose, it is true, are different in character to that of cotton, and it may be possible that they will germinate at temperatures several degrees lower than will cotton seed, but I am in hopes for the purposes we have in view they will serve our object. No experiments that the writer is aware of have been made to determine the germinating temperature of cotton seed. Experiments are now under way at the Alabama Agricultural Experiment Station at Auburn to solve this interesting problem.

The minimum temperature below which it is said seeds will not germinate has been given by Haberlandt as 4.75° C., or 40.6° F. Some seeds, however, may be made to start even below this temperature. Between the maximum and minimum germinating temperatures there is an optimum at which germination begins most speedily, and our table of soil temperatures shows that this point is reached very often. As a means of comparison I give Table XIV, taken from Sach's Botany, containing the germinating temperatures of certain well known plants.

TABLE XIV.—*Germinating temperatures.*

	Maximum.	Minimum.	Optimum.
	° F.	° F.	° F.
Barley	99.5	41.0	83.7
Flax		35.0	81.3
Indian corn	115.2	48.8	92.7
Lepium sativum		35.0	81.0
Pea		43.0	78.8
Pumpkin	115.2	56.7	92.7
Squash	115.0	51.8	92.0
Sunflower			88.7
Watermelon			99.5
Wheat	107.6	41.0	82.4

TABLE XV.—*Soil and air temperatures at Auburn and Uniontown, Alabama.*

SOIL TEMPERATURES.

April.

Years.	1 inch.			3 inches.			6 inches.			12 inches.			24 inches.			36 inches.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
Auburn.	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1889	85.5	50.0	68.6	83.5	51.0	68.1	79.9	53.0	66.6	73.0	56.5	64.1	68.5	59.0	63.1	64.5	57.5	60.9
1890	83.5	48.0	68.8	82.0	50.0	67.6	75.5	52.5	61.8	75.0	56.0	66.0	69.5	60.0	64.2	67.0	60.0	62.8
1891	87.5	34.0	67.7	86.0	37.5	66.5	83.0	40.0	65.0	76.0	43.5	62.5	69.5	51.0	61.9	66.0	54.0	60.0
Uniontown.																		
1889	69.0	51.0	61.4	67.0	53.0	61.3	66.0	55.0	61.2	64.5	57.0	66.0	63.5	57.0	60.4	62.5	56.5	59.7
1890	72.5	51.5	63.1	69.5	54.5	62.3	67.0	57.0	62.3	65.5	59.0	62.3	64.0	59.0	62.0	63.5	59.0	61.6
1891	74.0	38.5	62.3	70.0	41.5	61.5	68.5	46.5	61.0	67.0	50.5	60.6	65.5	54.0	59.9	64.0	56.0	59.4

May.

Years.	1 inch.			3 inches.			6 inches.			12 inches.			24 inches.			36 inches.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
Auburn.	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1888	91.0	58.5	74.0	90.5	59.5	74.0	86.0	63.5	73.0	81.5	65.0	71.5	75.5	67.5	71.5	71.5	66.5	68.0
1889	92.0	52.0	77.3	90.0	55.0	77.1	86.5	58.0	75.7	81.5	61.0	72.0	70.5	64.0	71.7	73.0	63.0	68.9
1890	94.5	52.0	76.2	90.0	54.0	75.5	86.0	59.0	73.9	81.0	62.0	72.0	75.0	66.0	70.6	71.0	66.5	68.6
1891	95.0	56.5	76.4	91.5	56.5	76.2	89.0	57.5	74.9	79.5	61.5	71.5	74.0	66.0	70.6	72.0	66.0	68.2
Uniontown.																		
1889	77.5	56.0	68.8	74.5	57.0	68.4	73.5	59.5	68.0	71.5	61.0	67.4	70.0	62.0	66.3	68.0	62.0	64.9
1890	75.5	56.0	69.0	74.0	58.5	68.2	72.5	62.0	68.1	71.5	64.0	68.0	70.0	65.0	67.4	69.0	64.5	66.5
1891	76.5	55.5	69.7	74.0	59.0	68.7	71.5	63.5	68.2	71.0	65.0	68.2	70.0	66.0	67.4	68.5	64.5	67.1

TABLE XV.—*Soil and air temperatures at Auburn and Uniontown*—Continued.

AIR TEMPERATURES.

Years.	April.			May.		
	Max.	Min.	Mean.	Max.	Min.	Mean.
	°	°	°	°	°	°
Auburn.						
1889	84.0	41.0	67.5	90.0	41.0	72.9
1890	86.0	45.0	65.6	87.0	48.0	72.4
1891	85.0	30.0	64.5	90.0	46.0	72.4
Uniontown.						
1889	82.0	38.0	62.5	89.0	45.0	70.1
1890	83.0	42.0	64.7	88.5	42.0	71.2
1891	83.0	30.0	63.5	89.0	45.0	69.6

The maximum temperature for Uniontown, it will be noticed, is lower than that for Auburn. This may be explained on the ground that the soil at the former place is more moist than is the soil at the latter place. The predominating soil at Auburn is of a sandy, open nature that readily gives up the moisture it receives from the rains and dews under the influence of the sun's rays, while the soil at Uniontown is calcareous in composition and receives and retains the water much longer and hence keeps down the temperature of the soil.

It is thus observed that under the influences of the occurrence of high temperatures and the generally prevailing fine weather after the 20th of April, the soil has become rapidly warmed and the seed quickly germinates and is generally very well started above the surface of the ground by the middle of May. The seed usually takes from five to twenty days to come up, if the soil is kept comparatively warm and the rains have been sufficient to supply the needed moisture. When the young plant is three or four weeks old the crop is thinned out to a stand. This takes place after the third or fourth leaf appears. In planting, sufficient seed are put in the drill to insure a good stand, and when "chopping out" is completed only so many plants are left standing in the field as will permit the roots of one to spread without interfering with those of another. This gives also ample room for the expansion of the limbs of the plants, so that the sunlight may penetrate to all the leaves, and thus insure the development of flowers and the rapid opening of the bolls that contain the fiber.

V.—THE GROWING PERIOD OF THE PLANT, AND ITS WEATHER CONDITIONS.

This period might be properly termed the season from "chopping out" to the appearance of the first boll. In the central portions of the cotton belt this time is generally from the first of June to the first of August. The first bloom opens early in June and the first boll forms early in August. During this period in the life of the plant there must be a large supply of sunshine, and only so much moisture as will furnish the plant with what it needs, and at the same time not make the soil so damp as to cause too rapid multiplication of surface roots nor cause too great a growth of what farmers term "weed," that is, rapid development of stalk and branches to the detriment of flowers and fruit. The atmosphere must not be very dry, but there must be that degree of moisture present that will readily become absorbed by the soil at night in the shape of dew, with occasional good showers through the season. The surface soil must be often stirred during this growing period so as to permit of free circulation of air through the soil, the penetration of the warm sun's rays, and the condensation of moisture from the atmosphere as it circulates over the soft land at night, and in the cool early morning. In this manner much of the moisture required by the roots will be secured, although rains may not be frequent; and at the same time an ample supply of sunshine and warmth will give the young buds vigor, and cause them to open promptly and bring forth healthy, well-developed bolls.

Experience has shown that the above conditions are required during the growing season to produce the best results in cotton culture. Now let us see what are the actual climatic conditions prevailing in the cotton belt during these months of June and July, and note in what respects they comply with the requirements and in what points they fail. To bring out these features the following tables, taken from the files of the Weather Bureau, have been prepared. A careful examination of these tables will present the striking fact that the weather conditions, during these two months, come very near filling all the requirements of the perfect cotton culture. It is true that some seasons are very unfavorable and poor crops are the result, but in the study of this question of climatology we must be governed by conclusions drawn from data covering a long term of years rather than confining our deductions to isolated years only.

During the months of June and July rains are not ordinarily heavy, and floods occur only at long intervals. Table XVI shows that the greatest normal rainfall is 6.83 inches for June at Cedar Keys, Fla., and for July it is 8.68 inches at the same place. The largest number of rainy days that occur during the two months usually take place at stations along the Atlantic and Gulf coasts. At stations in the interior the rain is not so frequent, but with the exception of some of the stations in Texas, there is never less than ten normal rainy days in each month, thus furnishing ample moisture for all the demands of the cotton plant while in its blooming season. Much rain during this period is decidedly injurious to the plant because the flowers are so singularly constituted that if water accumulates in the cup formed by the petals and sepals rapid decay will take place, caused by fermentation of the gelatinous substance generated at the base of the flowers, and the forms will shed off and the yield of the plant be correspondingly decreased. These flowers open in the early morning, just after the sun rises above the horizon, and remain expanded to the sun's rays until late in the evening, when the petals close and remain so until next morning when they open again.

At this stage of their development the color changes from a delicate cream to a light red. At the close of this day the petals fall off, leaving a small boll surrounded by the green sepals. Now, if the rains are frequent during this period the petals have their sensitive organisms greatly dulled, and the absence of the sunlight, so necessary for their activity, causes them to stick to the forming boll and decay rapidly follows. Much cloudy weather during this period is almost as injurious as continual rains, for the reasons already stated —the cotton plant is a sun plant. Now, a glance at our tables will show that the normal conditions throughout the cotton belt are very favorable for the growth of such a peculiarly delicate plant. If the season during April and May has been propitious the tap root is deep in the soil at this stage of the plant, and the supply of moisture brought up from below is amply sufficient for all demands if a shower falls occasionally.

This plant can stand a much longer drought while blooming than almost any other vegetation, and hence the fall of rain should not be more frequent than once in three or four days, and the showers should be very light, permitting as much as possible the largest amount of sunshine. In Table XIX, probability of rainy days, page 45, it will be noticed that the number of days on which rain is apt to fall during these two months does not exceed 51 per cent. at any point in the entire region of the cotton belt, and at most places it generally does not exceed 40 per cent. The average number of sunny days during June and July is 56 per cent. At many of the stations, however, the percentage of perfectly clear days is greater than that given above for the entire region. For instance, at Memphis, Tenn., it is 59 per cent.; at Vicksburg, Miss., it is 68 per cent.

In Table XVII, June and July temperatures, special attention is called to the close uniformity existing between the two months, and also how near the same temperature is furnished by all the stations occupying the southern portion of the cotton belt. This is found to be true also when the stations of each of the other two sections are compared with each other.

During this period of its growth the plant is forging ahead rapidly, making leaves and roots, and towards the middle of June flowers are opening in all directions of the cotton belt under the warm, invigorating influence of the atmosphere so favorably prevailing all over the country.

TABLE XVI.—*Precipitation for June and July in the cotton belt.*

Stations.	Normal precipitation.		Average number of rainy days.		Maximum precipitation.		Month and year.		Minimum precipitation.		Month and year.		Average number of cloudless days.		Average number of partly cloudy days.		Average number of cloudy days.	
	June.	July.	June.	July.	June.	July.	June.	July.	June.	July.	June.	July.	June.	July.	June.	July.	June.	July.
	Inches.	*Inches.*			*Inches.*	*Inches.*			*Inches.*	*Inches.*								
Charlotte, N. C	4.67	5.86	12.0	12.2	11.04	8.64	1886	1879	0.52	1.68	1890	1888	8.7	7.8	13.3	14.7	8.0	8.5
Hatteras, N. C	4.86	6.33	10.6	11.1	11.91	10.51	1889	1884	0.63	2.21	1882	1879	10.2	11.3	6.0	13.4	13.8	6.3
Kittyhawk, N. C	4.81	5.81	10.8	11.4	10.97	15.36	1877	1882	1.44	0.94	1879	1885	10.6	9.7	13.5	15.3	5.9	6.0
Wilmington, N. C	5.94	7.27	12.0	15.1	12.44	21.12	1876	1886	2.87	1.95	1872	1875	8.7	8.8	14.4	14.4	7.9	7.8
Charleston, S. C	5.08	6.95	11.6	12.4	14.98	13.74	1876	1874	1.20	1.05	1891	1875	8.1	9.0	13.4	14.5	8.5	7.5
Atlanta, Ga	4.41	4.63	12.0	10.0	10.73	14.11	1884	1887	1.12	0.56	1890	1881	8.0	8.8	14.6	14.9	7.4	7.3
Augusta, Ga	4.24	5.17	11.3	11.2	9.65	10.10	1886	1889	1.21	1.79	1879	1888	8.1	8.8	14.7	14.6	7.2	7.6
Savannah, Ga	6.75	5.34	13.1	12.8	18.79	10.14	1876	1874	0.91	0.82	1881	1888	7.3	7.9	14.9	16.2	7.2	6.9
Cedar Keys, Fla	6.83	8.08	11.3	14.5	10.98	11.72	1885	1886	1.69	4.11	1881	1888	6.2	7.7	16.6	14.0	7.2	9.3
Jacksonville, Fla	6.03	6.36	14.8	16.7	16.75	14.97	1871	1886	1.25	0.14	1879	1875	7.7	8.8	15.0	16.1	7.3	6.1
Pensacola, Fla	5.85	6.55	12.4	14.7	14.11	13.68	1887	1890	2.21	2.20	1890	1888	10.0	9.1	14.6	15.8	5.4	6.1
Chattanooga, Tenn	4.37	3.72	14.3	13.1	9.20	6.18	1884	1891	1.69	2.06	1879	1883	8.8	8.9	14.4	14.6	6.1	6.7
Knoxville, Tenn	4.29	4.37	13.3	12.7	6.68	8.59	1872	1884	1.99	2.12	1879	1877	8.4	10.2	15.0	14.5	6.6	6.3
Memphis, Tenn	5.00	3.29	11.6	10.0	18.16	6.22	1877	1877	1.04	0.47	1887	1874	9.2	11.6	14.7	13.8	6.1	5.6
Nashville, Tenn	4.34	4.54	11.2	10.5	7.69	9.43	1886	1878	2.23	0.46	1890	1890	6.4	8.9	17.1	16.1	6.5	6.0
Auburn, Ala	5.28	4.37	10.2	10.0	11.52	21.09	1884	1887	1.89	2.38	1855	1856	6.4	7.5	14.0	16.6	9.6	6.9
Mobile, Ala	6.06	6.60	12.9	15.1	13.56	13.36	1888	1872	2.35	2.77	1879	1881	8.1	7.0	15.0	16.3	6.9	7.7
Montgomery, Ala	4.92	4.24	12.3	12.0	11.08	7.54	1873	1885	1.94	0.87	1875	1883	7.7	7.5	13.5	15.8	8.8	7.7
Vicksburg, Miss	4.35	4.15	10.9	11.3	9.83	10.19	1889	1882	0.40	1.58	1882	1886	9.3	9.7	15.0	15.1	5.7	6.2
Little Rock, Ark	4.39	3.88	11.6	10.0	9.28	9.23	1886	1891	1.96	1.18	1882	1887	10.1	11.3	14.6	14.1	5.3	5.6
Fort Smith, Ark	4.27	4.09	10.0	8.7	7.67	9.88	1888	1891	2.10	1.77	1882	1882	11.6	13.9	13.0	12.2	5.4	4.9
New Orleans, La	6.66	6.38	13.8	15.8	12.05	12.93	1883	1874	2.84	2.02	1881	1888	8.1	8.0	15.5	17.4	6.4	5.6
Shreveport, La	3.57	3.68	8.4	8.7	7.97	11.38	1889	1882	0.38	0.06	1881	1884	9.3	11.4	15.7	15.1	5.0	4.5
Brownsville, Tex	3.25	2.22	6.9	4.5	13.80	6.58	1887	1878	0.26	0.22	1891	1885	13.5	15.1	12.5	12.8	4.0	2.5
El Paso, Tex	0.53	2.17	4.0	8.4	2.63	8.18	1885	1881	0.02	0.06	1881-'83	1891	19.5	13.5	9.5	14.8	1.0	2.7
Fort Davis, Tex	2.09	3.31	8.2	10.0	3.64	10.11	1890	1880	0.07	0.35	1881	1884	15.7	15.4	12.5	11.6	1.8	4.0
Fort Elliott, Tex	3.18	2.32	6.9	5.3	9.82	5.65	1885	1882	0.10	0.49	1881	1881	13.2	14.5	12.8	13.1	3.7	3.4
Galveston, Tex	5.76	3.04	7.2	8.6	11.89	9.31	1871	1874	0.03	0.34	1881	1872	11.7	13.2	13.8	14.1	4.5	3.7
Indianola, Tex	2.64	2.29	5.3	6.6	7.56	5.76	1884	1874	0.21	0.32	1885	1883	12.2	14.7	16.8	15.0	1.0	1.3
Palestine, Tex	3.51	2.82	7.9	7.1	7.00	6.52	1889	1882	0.83	0.06	1882	1884	8.7	13.9	16.1	13.6	5.0	3.5
Rio Grande City, Tex	2.27	1.29	4.8	3.6	8.08	5.98	1887	1878	0.00	0.00	1885	1884	14.1	19.0	12.1	8.7	3.8	3.3
San Antonio, Tex	2.46	2.68	6.3	6.0	4.79	6.56	1889	1885	0.00	0.12	1881	1879	8.4	10.8	16.1	16.2	5.5	4.0
Corsicana, Tex	3.04	2.48	6.3	6.6	5.72	3.82	1889	1878	0.00	0.60	1881	1891	9.1	11.3	16.5	15.6	4.4	2.4

TABLE XVII.—*Temperature for months of June and July, exhibiting the uniform range.*

Stations.	Monthly mean.		Mean maximum.		Mean minimum.		Maximum.				Minimum.			
							June.		July.		June.		July.	
	June.	July.	June.	July.	June.	July.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.
	°	°	°	°	°	°								
Aberdeen, Miss	76.6	78.7	86.8	89.2	66.4	68.1	98	1890, '91	98	1884, '85, '87, '88, '90	40	1889	55	1885
Allendale, S. C	77.6	80.1	88.8	90	66.4	70.2	102	1887	105	1883	43	1884	52	1884
Atlanta, Ga	75.7	78.3	84.3	86.7	67.2	70	98	1890	100	1887	39	1889	58	1882, '86, '91
Auburn, Ala	76.7	78.0	84.8	84.8	68.8	71.2	97	1881	100	1881	46	1889	59	1882
Augusta, Ga	79.2	82.2	89.1	91.8	69.3	72.6	103	1887	105	1878	46	1889	62	1876, '85
Batesville, Miss	78.3	81	88.4	91.6	68.2	70.4	104	1883	101	1883, '85	46	1889	58	1890, '91
Branchville, S. C	78.3	80.3	88.9	90.2	67.7	70.6	102	1890	103	1887	47	1889	56	1889, '90
Brinkley, Ark	76.4	80.4	88.9	92.4	63.9	68.4	100	1884	105	1885, '88	30	1884	42	1884
Brookhaven, Miss	78.9	81.1	90.4	92.5	67.4	69.7	100	1885, '91	104	1888	42	1889	57	1891
Brownsville, Tex	82.7	83.8	90.2	91.3	75.1	70.3	102	1878	98	1883	63	1877	65	1887
Cedar Keys, Fla	80.1	82	86.4	87.9	74.3	77.5	94	1880	96	1885	56	1889	68	1886
Charleston, S. C	79.4	82	86.4	88.9	72.4	75.1	100	1877, '80, '87	104	1879	51	1889	65	1886, '91
Cheraw, S. C	77.7	80.6	89.5	92.3	66	68.9	104	1887	108	1887	49	1884	52	1885
Chester, S. C	78.8	80.5	89.8	91.8	67.7	69.3	105	1887	110	1887	44	1889	57	1885
Chattanooga, Tenn	75.7	78.5	85.3	87.9	66.1	69.2	98	1889	101	1879	39	1889	56	1885
Columbus, Miss	80.7	82.6	93.4	95.2	68.1	70.1	105	1887, '91	107	1883	43	1889	58	1885, '86
Corinth, Miss	81.5	79.2	88.1	90.9	64.9	67.5	101	1887	100	1886, '87, '88	36	1889	52	1884, '88
Corsicana, Tex	80.4	84.3	92.1	95.7	70.4	73.7	104	1881	108	1881	50	1877	59	1877
Coushatta, La	80.7	82.4	91.8	94.1	69.7	70.8	103	1886	104	1883	45	1883	59	1891
Charlotte, N. C	75.9	78.6	85.4	87.9	66.3	69.3	102	1887	102	1887	45	1889	55	1891
Devall Bluff, Ark	76.8	79.4	88.2	91.1	65.5	67.7	99	1887	100	1885	48	1889	53	1887
Edwards, Miss	80.3	82.5	90.7	92.4	69.9	72.6	100	1891	101	1890	48	1889	63	1888, '91
El Paso, Tex	81.5	83.4	97.6	98	65.7	68.7	113	1883	111	1884, '86	50	1881	56	1880
Fort Davis, Tex	78.3	76.8	90.4	89.2	62.2	64.3	111	1881	110	1881	49	1881, '86	53	1881
Florence, S. C	78.3	80.6	90.3	91.7	66.3	69.6	103	1887	105	1887	49	1883	57	1890
Fort Elliott, Tex	73.7	78.1	85.6	90.6	61.8	65.7	100	1880, '81, '88	108	1889	44	1880, '82	49	1880
Fort Smith, Ark	77.2	81.5	87.6	92.6	66.8	70.3	101	1882	104.5	1884	50	1882	56	1891
Galveston, Tex	82.3	84.3	87.4	89.6	77.1	79	97	1875	97	1875	64	1877	67	1887
Hardeeville, S. C	79.1	81.5	89.9	91.9	68.3	71.2	103	1887	103	1883, '87	46	1889	53	1883
Hatteras, N. C	74	77.6	79.2	82.6	68.9	72.6	91	1882	92	1881	57	1876, '84	61	1885
Hernando, Miss	78.1	80.4	89.2	92.3	67.1	68.4	105	1883	108	1883	49	1883	49	1883
Jackson, Miss	74.9	81.9	81.5	92.5	68.4	71.3	102	1885, '91	103	1884	44	1889	60	1885
Jacksonboro, S. C	77.5	79.4	89.8	89.9	65.2	68.9	105	1887	104	1887	44	1889	53	1885, '88
Jacksonville, Fla	80.7	82.9	89	91.1	72.5	74.6	101	1880	104	1879	54	1889	66	1890, '91
Kingstree, S. C	77.9	79	90.1	90.1	65.8	67.9	103	1887	103	1887, '88	44	1887	51	1885
Kittyhawk, N. C	74.2	78.3	80.8	84.5	67.6	72	99	1880	107	1887	52	1884	59	1888
Knoxville, Tenn	74.2	77.4	84.1	87.1	64.3	67.4	96	1874, '80, '87	100	1879, '87	44	1889	52	1885

Lake, Miss	76.4	80.4	90.1	91.7	62.7	69.2	100	1891	102	1887	40	1889	47	1885
Little Rock, Ark	77.8	81.1	86.7	90.1	68.8	72.1	98	1882	101.3	1884	51	1889	60	1891
Macon, Miss	80	81.9	92.8	94.3	67.3	69.6	102	1887, '91	103	1883	42	1889	50	1890
Malvern, Ark	76.1	81.6	89.6	93.9	65.6	69.4								
Memphis, Tenn	78	81.4	87	90.1	69	72.7	100	1881	99	1875, '79, '81, '87	50	1889	58	1891
Mobile, Ala	80.4	82.6	88.8	90.8	72.1	74.4	100	1877, '82	101	1881, '83	50	1889	64	1882
Monroe, La	79.7	82.2	90	92.3	69.5	72.1	99	1887, '91	99	1884, '87, '88	46	1889	55	1887
Montgomery, Ala	80.4	82.6	89.8	91.9	71.1	73.3	105.5	1881	107	1881	48	1889	61	1882
Nashville, Tenn	75.9	79.6	85.3	89.1	66.5	70.1	99	1874	101	1874, '79, '81	46	1889	56	1882, '91
Natchitoches, La	79.3	81.7	88.3	90.8	70.3	72.5	99	1891	98	1887, '89, '90	52	1889	63	1888
New Orleans, La	80.6	82.7	87.2	89.1	74.1	76.2	97	1881	96	1877, '87, '88, '90	58	1889	68	1890, '91
Okolona, Miss	80.0	82.8	92.4	95.1	67.6	70.5	105	1885, '87	106	1883, '85	44	1889	58	1891
Palestine, Tex	79.0	82.3	88.4	92.0	69.7	72.6	97	1886	102	1887	55	1882, '89	63	1882
Pensacola, Fla	79.8	81.4	86.1	87.9	73.6	74.8	97	1881	99	1887	55	1889	64	1882
Prescott, Ark	77.9	81.1	88.6	92.7	67.2	69.6	102	1883	103	1884	53	1885	51	1884
Rio Grande City, Tex	85.5	87.4	96.7	99.2	74.3	75.6	109	1883	110	1884	62	1877, '83, '90	62	1877, '83
Savannah, Ga	79.6	82.4	87.5	90.1	71.7	74.6	100	1880, '87	105	1879	59	1877, '84	64	1891
San Antonio, Tex	81.2	83.5	91.2	94.1	71.2	72.9	103	1883	104	1882, '91	53	1877	58	1878
Shreveport, La	81.0	83.8	91.0	93.7	71.0	73.9	104	1875	107	1875	55	1877, '89	64	1877, '80, '82, '91
Spartanburg, S. C	75.6	78.4	87.6	90.6	63.6	66.1	102	1888	104	1887, '88, '89	42	1887, '89	46	1891
Saint Matthews, S. C	78.2	80.7	88.7	90.7	67.7	70.8	105	1887	106	1887	46	1889	55	1885
Saint Georges, S. C	78.8	80.4	90.4	91.7	66.4	69.1	104	1887	105	1887	48	1884, '89	55	1885
Texarkana, Ark	77.0	81.3	89.1	93.2	64.9	69.3	100	1886	102	1884	37	1884	54	1886
Vicksburg, Miss	79.5	82.4	89.0	91.7	70.5	73.0	101	1881	100	1878, '81	52	1889	62	1881, '91
Waynesboro, Miss	79.2	81.8	91.1	93.4	67.4	70.2	104	1883, '91	106	1883	41	1889	55	1883
Wilmington, N. C	76.2	79.5	84.4	86.7	67.9	72.2	100	1880, '90	103	1879	51	1884	58	1890

A remarkable fact concerning these two months consists in the very uniform range of not only the normal temperature but also in the annual means of the months. In June there are only 10° between the greatest normal and the least; while in July there are only 8° difference. When one year is compared with another the following results become apparent: For the sake of contrast one station from each of the sections of the belt (north, middle, and southern) has been selected—

Memphis.—The mean temperature for June, during a period of twenty years, ranged from 70° to 80°, and for eighteen years was above 75°. For July the range was from 77° to 84°. Fifteen of the twenty years furnished mean temperatures above 80°.

Montgomery.—This station has a record of nineteen years. The range of the mean temperature was in June from 77° to 83°; in July it was from 79° to 86°. In June, for thirteen years, the mean temperature was above 80°, while in July, for sixteen years, it was above 80°.

Savannah.—For eighteen years the mean temperature in June ranged between 71° and 83°. For nine years it was above 80°, and for sixteen years it was above 78°. During July the temperature ranged between 79° and 85°. Eight of the twenty years covering the records gave a temperature above 84°.

These records show a very uniform condition of the temperature that is so suitable for the successful cultivation of the cotton during its flowering period. The air is well warmed by the sun's rays and the thermometer often reaches 90°. What has already been shown in regard to the mean temperature is true in relation to the mean maxima and mean minima. At New Orleans for a period of twenty years the mean maximum temperature in June ranged between 84.6° and 91.3°. For ten years there was less than 1° difference between the mean maxima temperatures. In July out of eighteen years thirteen of them gave less than 3° range between the mean maxima, and the mean minima temperatures for the same period of time ranged between 70.3° and 78° for June and 74.5° and 77.8° in July; thus showing, what has already been said, that practically the same mean temperature, so far as the influence on plants is concerned, may occur from year to year. This fact may be more strikingly exhibited by means of the following comparison between the mean maxima and the maxima temperatures at some of the stations in the cotton belt:

TABLE XVIII.—*Maximum and mean maximum temperatures at certain stations in the cotton belt for the month of July.*

Stations.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.
	°	°	°	°	°	°	°	°	°	°	°	°	°
Atlanta	97	94	98	90	95	90	91	92	100	94	95	96	90
	87.0	87.7	89.8	83.6	89.4	85.1	86.5	85.6	85.6	88.4	87.0	87.3	84.0
Fort Smith	......	......	......	100	100	104	99	103	104	100	98	101	97
	......	......	......	91.9	96.4	96.7	91.6	91.5	95.8	92.6	91.2	94.7	87.1
Knoxville	100	94	99	89	96	91	94	94	100	93	92	95	90
	90.2	85.6	90.3	82.4	87.0	85.1	87.3	84.6	89.0	87.4	86.1	87.4	82.3
Memphis	99	95	99	93	97	97	96	96	99	97	94	98	94
	93.0	88.1	92.7	83.9	89.8	90.7	90.8	89.5	91.1	91.8	88.9	90.3	88.7
Kittyhawk	......	96	99	96	100	97	98	91	107	100	100	96	89
	......	83.2	83.4	79.7	86.6	84	89.7	81.5	91.4	83.5	86.8	83.8	80.6
Charleston	104	97	103	94	101	95	94	92	98	100	97	92	95
	89.5	90.9	90.5	89.2	92.1	88.9	89.1	86.8	88.7	87.1	87.4	86.3	86.5
Montgomery	101	100	107	95	99	95	98	95	100	98	99	97	94
	92.8	93.1	95.9	87.8	94.2	90.9	91.0	90.9	90.7	92.5	91.0	90.7	88.7
Palestine	......	......	......	98	97	98	95	97	102	94	99	97	96
	......	......	......	90.0	92.9	94.0	91.2	91.8	94.6	89.8	92.1	92.6	90.5
Vicksburg	98	97	100	96	96	99	99	96	95	97	94	99	93
	93.2	91.3	97.4	83.9	92.8	93.8	92.4	89.8	89.6	92.4	89.5	91.6	87.7
Brownsville	95	95	96	94	98	95	94	93	92	94	94	94	95
	92.1	89.8	92.7	91.1	93.9	92.2	91.9	89.1	89.3	90.8	91.0	91.7	91.3
Jacksonville	104	97	99	94	98	96	95	94	100	90	97	96	95
	92.8	92.4	91.9	89.0	92.2	90.6	91.3	89.3	91.3	90.4	89.7	89.5	89.4
Mobile	100	98	101	97	101	96	94	93	98	97	95	96	93
	91.0	92.0	94.0	89.1	95.7	89.7	89.5	87.2	90.1	90.7	88.7	88.0	87.4
New Orleans	91	92	95	92	94	95	92	93	96	96	95	96	92
	87.9	88.3	90.1	86.6	90.3	90.7	90.1	88.1	90.2	90.7	90.1	88.6	87.7

TABLE XIX.—*Percentage of mean cloudy days and probability of rainy days in the cotton region, compiled from the records covering the period from* 1871 *to* 1888.

PERCENTAGE OF CLOUDY DAYS.

Stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Northern section.	%	%	%	%	%	%	%	%	%	%	%	%
Atlanta, Ga	58	53	46	45	46	52	46	50	43	42	46	51
Charlotte, N. C	60	52	50	49	52	53	53	53	49	43	45	51
Chattanooga, Tenn	61	58	52	46	46	47	44	48	44	43	47	57
El Paso, Tex	29	30	27	23	24	28	37	35	29	25	31	28
Fort Davis Tex	31	31	31	26	28	30	35	36	36	31	32	29
Fort Elliott, Tex	31	33	34	37	41	37	34	33	30	32	31	32
Fort Smith, Ark	50	56	50	49	41	44	38	41	38	40	45	51
Knoxville, Tenn	62	57	53	48	45	49	46	45	41	39	52	54
Little Rock, Ark	54	56	51	44	46	42	39	37	37	37	44	52
Memphis, Tenn	58	57	51	47	46	45	42	40	40	38	51	56
Nashville, Tenn	64	61	56	53	50	52	48	44	44	42	53	62
Middle section.												
Auburn, Ala	59	55	47	46	45	51	48	49	44	41	46	50
Augusta, Ga	51	49	45	44	42	48	47	50	46	37	45	48
Charleston, S. C	50	47	43	41	42	49	48	50	47	37	42	47
Green Springs, Ala	48	35	29	30	18	21	19	20	16	19	30	37
Hatteras, N. C	56	48	46	43	43	46	42	46	41	42	47	49
Kittyhawk, N. C	54	47	48	49	43	44	44	52	45	44	48	51
Montgomery, Ala	60	55	47	46	44	51	49	49	45	41	47	50
Palestine, Tex	53	55	50	52	47	43	37	38	39	39	47	52
Shreveport, La	58	55	51	49	46	45	40	36	37	37	46	53
Vicksburg, Miss	58	55	49	44	43	42	42	41	45	38	48	54
Wilmington, N. C	54	51	47	44	46	49	50	52	49	41	46	49
Southern section.												
Brownsville, Tex	......	56	56	55	46	39	34	41	47	41	52	53
Cedar Keys, Fla	45	38	41	36	40	50	52	49	41	35	37	43
Galveston Tex	54	53	51	48	47	41	38	41	42	37	45	51
Indianola, Tex	53	54	56	50	49	39	37	37	39	37	46	54
Jacksonville, Fla	49	45	40	40	40	47	43	44	48	43	45	47
Mobile, Ala	54	50	48	47	43	49	49	49	44	40	45	51
New Orleans, La	53	50	46	48	45	46	48	46	45	39	47	53
Pensacola, Fla	56	49	44	44	42	45	47	49	42	40	46	51
Rio Grande City, Tex	......	47	49	45	40	36	26	38	47	39	46	43
San Antonio, Tex	51	54	53	52	53	45	45	44	44	43	50	49
Savannah, Ga	50	48	43	42	42	49	48	50	48	40	45	46

TABLE XIX.—*Percentage of mean cloudy days, &c.*—Continued.

PROBABILITY OF RAINY DAYS.

Stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Northern section.												
Atlanta, Ga	47	39	38	35	33	38	33	41	28	26	34	39
Charlotte, N. C	46	38	38	34	39	41	39	36	25	27	31	38
Chattanooga, Tenn	49	47	41	35	36	43	41	39	32	27	31	40
El Paso, Tex	11	14	9	4	8	12	29	28	21	15	12	11
Fort Davis, Tex	11	9	10	12	17	29	32	33	29	16	14	8
Fort Elliott, Tex	9	11	15	18	29	25	23	26	18	19	9	11
Fort Smith, Ark	24	29	28	38	29	32	29	26	20	23	26	25
Knoxville, Tenn	47	42	41	39	39	43	41	37	26	28	32	39
Little Rock, Ark	35	37	38	33	37	37	31	31	22	24	32	32
Memphis, Tenn	41	39	41	37	34	36	29	27	25	24	36	37
Nashville, Tenn	42	40	40	37	34	40	35	29	27	24	35	39
Middle section.												
Auburn, Ala	40	38	35	30	31	38	33	40	26	23	30	38
Augusta, Ga	38	37	35	29	30	37	45	39	26	24	31	33
Charleston, S. C	38	35	32	27	28	36	36	42	36	26	27	32
Green Springs, Ala	28	31	30	27	19	27	22	26	16	18	22	30
Hatteras, N. C	52	36	39	34	31	37	33	44	25	22	32	41
Kittyhawk, N. C	50	38	43	39	33	33	36	43	26	30	37	36
Montgomery, Ala	40	38	35	31	31	40	34	36	24	21	29	36
Palestine, Tex	36	36	31	32	32	26	24	23	25	23	31	33
Shreveport, La	38	39	34	33	27	33	33	22	25	22	31	34
Vicksburg, Miss	41	39	34	32	26	34	31	29	25	22	33	36
Wilmington, N. C	42	39	36	31	32	38	41	47	33	26	28	36
Southern section.												
Brownsville, Tex	31	28	31	12	21	22	18	24	36	25	25	23
Cedar Keys, Fla	31	23	25	19	23	38	46	41	29	23	22	28
Galveston, Tex	38	36	31	23	23	27	33	33	34	25	31	38
Indianola, Tex	32	28	33	19	18	22	22	28	35	24	29	32
Jacksonville, Fla	31	33	25	24	32	45	46	46	47	32	26	25
Mobile, Ala	37	31	34	26	27	44	41	41	31	22	25	33
New Orleans, La	36	33	32	27	32	46	51	47	36	24	32	39
Pensacola, Fla	42	25	31	26	24	42	48	45	31	22	29	35
Rio Grande City, Tex	19	12	15	11	21	15	11	21	24	18	16	18
San Antonio, Tex	31	29	24	26	26	21	19	22	28	23	25	24
Savannah, Ga	34	34	29	30	29	43	38	43	38	25	25	31

VI.—CHARACTER OF WEATHER BEST SUITED FOR THE PRODUCTION OF FIBER DURING ITS PROCESS OF FORMATION.

The first boll generally opens early in August, the interval from the first bloom to the first boll being about 40 to 50 days, the shorter interval being required later in the season. The plant continues to bloom during the month of August and until the latter part of September, but its powers in this regard are steadily reduced as the vitality goes more and more into growing the already formed bolls and bringing them to maturity. In the Southern States the cotton plant is decidedly an annual, whatever may have been its condition in its original form, and the work of perfecting its seed completes its life. It is a question of considerable interest, that if the frosts of autumn could be delayed from year to year until late in the winter, how long would the cotton plant continue to bloom and mature bolls of well-developed fiber?

During this period in the history of the cotton plant there must be an abundance of sunshine and a small amount of moisture. At this time the plant has reached its full height and the largest share of its vitality must go towards making seed and developing fiber. If much rain occurs at this stage in its life three deleterious results will take place: First, the "weed" or stem, leaves, and branches will begin rapidly to multiply to the detriment of the fruit. The plant will stop blooming and the squares already formed will shed because of the too rapid growth of the parts of the branches to which they are attached. Second, the bolls already formed will begin to decay, caused by the surplus water absorbed by them, and thus rendered unable to open, since it takes a large per cent. of warmth and sunlight to cause the bolls to open, they will be destroyed. Third, the fiber in the bolls already opened, when the rain season begins will be beaten out on the ground and lost or badly stained. It is therefore best for the condition of the cotton plant that much dry weather must prevail during the months of August and September. There is not much necessity for rains and only enough moisture is required to satisfy the demands of the plant as it supplies new material to the growing bolls and opening flowers. Much of this moisture, however, can be secured through the roots, if they have been forced deep into the soil by seasonable weather during the early period of the plant, as already mentioned in the first portions of this monograph. An occasional light shower, to prevent the soil from becoming too dry, will suit all requirements.

Although droughts occur frequently during the months of July and August, still the normal results indicate for the entire cotton belt 43.5 per cent. of cloudy days while the probability of rainy days is 34.5 per cent. The sun is likely, under these conditions, to shine unclouded 56.5 days in the 100. This character of the season is most propitious for the plant in its flowering and boll-forming period.

The above table of cloudy days and probability of rainy days, simply shows, in the case of rain, how many days in 100 may produce 0.01 of an inch or more of rain. In September the probability of rain in the northern section of the cotton belt is as 1 : 4, or one day in four may produce rain. The normal rainfall for this month in the same region of the cotton belt is 3.03 inches. So that the eight days of precipitation may produce on an average 0.38 of an inch each day. This indicates a dry month in its normal condition, and therefore very favorable for gathering the staple. The large per cent. of sunshine, 61 per cent., causes the bolls to open rapidly and preserves the fiber in its purest whiteness. The tables of rainfall and days of rain and cloudiness show that this character of weather continues through October; thus furnishing two months of fine season for gathering the crops. In the central portion of the belt we find a similar condition of the cast of the sky. The probability of rain in September is 27 per cent. out of 100; and the per cent. of cloudy days is 44, or 66 per cent. of sunshiny weather. The normal rainfall for this section for September is 4.74 inches, or 0.59 of an inch for each of the eight days of rain. There is more rain throughout the southern belt than in either of the other two. The normal is 5.72 inches, the probability of rain is 1 : 3, or 33 days in 100 may produce rain.

The per cent. of cloudy days is 44.8. So that during September there is a probability of 55 days of sunshiny weather in 100.

An interesting fact is brought out in the study of this table of percentages. By a glance at Chart VII, locating the limits of the cotton belt, it will be noticed that a large portion of the western and southwestern parts of Texas produce no cotton, although attempts have been made to extend the belt much beyond its present terminus. An explanation of this failure will be readily understood when it will be seen that the probability of rainy days throughout the year is so small at all stations that this scarcity of rain, coupled with the low range of temperature given for these stations, will discourage all efforts to grow cotton in that section of the country.

TABLE XX.—*Normal condition of the atmosphere during August and September, as regards the amount of sunshine and rainfall.*

Stations.	Number of cloudless days.		Number of partly cloudy days.		Number of cloudy days.		Rainfall (in inches).		Number of days of rainfall.	
	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.
Charlotte, N. C	9.1	10.5	12.3	10.8	9.6	8.7	5.46	3.24	10.6	8.9
Hatteras, N. C	11.2	13.6	11.8	11.2	8.0	6.2	6.52	6.61	13.8	7.8
Kittyhawk, N. C	8.4	11.5	14.9	11.3	7.7	7.2	7.48	5.18	12.9	5.4
Wilmington, N. C	8.5	10.4	13.5	10.9	9.0	8.7	7.80	0.70	13.7	9.8
Charleston, S. C	9.2	10.6	13.5	10.8	8.3	8.6	6.43	6.06	12.5	9.8
Atlanta, Ga	8.0	12.6	15.0	11.7	8.0	5.7	4.39	4.21	13.1	9.7
Augusta, Ga	8.2	10.2	15.0	12.1	7.8	7.7	4.83	3.74	10.8	8.0
Savannah, Ga	7.7	8.7	15.3	11.7	8.0	9.6	7.65	5.89	13.5	11.5
Cedar Keys, Fla	8.7	11.9	13.9	12.9	8.4	5.2	7.72	5.37	13.1	10.1
Jacksonville, Fla	8.7	9.1	16.4	12.2	5.9	8.7	6.80	8.06	15.5	14.1
Pensacola, Fla	10.5	12.4	14.0	12.3	6.5	5.3	8.13	5.25	13.6	10.0
Chattanooga, Tenn	8.6	11.3	15.4	12.1	7.0	6.6	4.16	4.24	13.2	10.9
Knoxville, Tenn	10.3	13.5	14.0	9.5	6.7	7.0	4.28	3.06	12.6	9.6
Nashville, Tenn	11.2	11.4	14.2	11.6	5.6	7.0	3.62	3.83	9.4	9.3
Memphis, Tenn	13.7	13.0	11.7	10.0	5.6	7.0	3.82	3.23	9.9	8.6
Auburn, Ala	9.4	8.9	15.0	13.3	6.6	7.8	4.20	3.29	12.4	7.5
Mobile, Ala	8.1	11.2	15.9	12.0	7.0	6.8	6.41	5.06	12.8	9.5
Montgomery, Ala	8.3	11.7	16.3	10.7	6.4	7.6	3.80	3.11	12.0	8.6
Vicksburg, Miss	11.2	12.0	15.1	10.0	4.7	8.0	3.50	3.85	8.7	9.1
Little Rock, Ark	14.5	13.4	12.4	11.6	4.1	5.0	3.92	3.23	8.9	8.4
Fort Smith, Ark	15.3	14.9	9.6	8.6	6.1	6.5	3.65	3.61	8.4	8.1
New Orleans, La	8.1	10.9	17.9	13.1	5.0	6.0	6.02	4.82	14.5	10.6
Shreveport, La	13.6	13.9	13.9	9.7	3.5	6.4	2.05	4.25	5.7	8.3
Brownsville, Tex	12.4	11.1	15.1	12.8	3.5	6.1	3.90	7.73	7.3	11.5
El Paso, Tex	15.0	16.7	11.7	8.9	4.3	4.4	1.87	1.22	9.4	5.3
Fort Davis, Tex	14.0	13.7	12.6	10.5	4.4	5.8	4.17	2.90	10.8	7.4
Fort Elliott, Tex	16.1	17.1	9.9	9.2	5.0	3.7	3.27	1.77	8.3	5.3
Galveston, Tex	13.3	12.6	12.9	10.7	4.8	6.7	2.94	7.07	10.3	11.0
Indianola, Tex	13.4	11.8	16.6	14.8	1.0	3.4	3.88	7.01	8.5	12.8
Palestine, Tex	13.0	12.9	14.8	10.5	3.2	6.6	2.51	3.21	6.7	8.2
Rio Grande City, Tex	14.6	11.5	10.7	12.1	5.7	6.4	2.94	3.78	4.9	9.4
San Antonio, Tex	8.7	10.2	18.3	11.8	4.0	8.0	3.45	4.16	6.7	9.7
Corsicana, Tex	14.1	12.3	14.5	10.9	2.4	6.8	1.60	3.09	4.7	5.6

VII.—THE PICKING SEASON AND ITS WEATHER.

The months of autumn are spent in gathering the staple, and by the end of November, if the season is favorable, almost the entire crop will be picked. All that the cotton planters desire during this period of the year is that frost will be delayed as late as the last week in November, and that after the middle of September heavy rainstorms will not occur, but that showers, if they come at all, shall be light and not frequent. This condition of the atmosphere will enable the pickers to gather the cotton as fast as it opens, in all its beautiful whiteness, unsullied by dampness, mold, or dirt. It is not often in the South that heavy rains occur in autumn, and monthly averages seldom go above 3.50 inches, but more frequently fall below 2.00 inches. The winds are also generally light so that the cotton is not greatly damaged by being driven out on to the ground and stained.

It is a trite saying among the farmers that all flowers that open after the 25th of September will fail to produce mature bolls, unless the season is unusually prolonged into the winter months. This is based on the idea that frosts usually come early in November, and together with cool nights, preceding the killing frosts, cause the plant to lose a large part of its growing vitality and the young bolls will stop developing before the seed and fiber are matured.

Table XXI has been prepared to show the time of occurrence of frosts in the cotton belt. The results are averaged for the entire region. In the extreme southern portions of the belt the frost will come later than in the more northern parts of the section under consideration. For instance, frosts may be expected along the coasts of Georgia and Alabama any time after November 15, while at Atlanta, Starkville, Vicksburg, and Palestine killing frost will come generally as soon as November 1. At Charlotte, Chattanooga, and Nashville it is as early as October 15.

TABLE XXI.—*Dates of killing frosts in the cotton belt.*

Years.	October.	November.	December.	Years.	October.	November.	December.
1832	20			1862			
1833	21			1863	24		
1834	20			1864			
1835		12		1865	20		
1836				1866			
1837	26			1867		26	
1838				1868		24	
1839				1869		21	
1840		14		1870		18	
1841	25			1871		29	
1842	25			1872		15	
1843				1873		7	
1844		14		1874			7
1845	12			1875			1
1846	19			1876		26	
1847		30		1877		19	
1848		1		1878		20	
1849		26		1879		21	
1850		17		1880		13	
1851		6		1881		23	
1852		27		1882		20	
1853	*			1883			12
1854		14		1884		24	
1855	25			1885		1	
1856	8			1886		13	
1857				1887		16	
1858	7			1888		18	
1859				1889		20	
1860	13			1890		17	
1861			24	1891			

* 14, 21, 25.

TABLE XXII.—*Temperature for months of August and September.*

Stations.	Monthly mean.		Mean maximum.		Mean minimum.		Maximum.				Minimum.			
							August.		September.		August.		September.	
	August.	September.	August.	September.	August.	September.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.
	°	°	°	°	°	°								
Aberdeen, Miss	77.2	72.4	87.9	83.5	66.5	61.4	100	1885	99	1887	44	1891	40	1889
Allendale, S. C	79.1	75.5	88.9	84.5	69.3	66.5	102	1883	95	1887	54	1884	41	1887, 1888
Atlanta, Ga	76.3	71.1	84.3	78.8	68.4	63.4	96	1881, 1888	95	1887	55	1887, 1891	43	1888
Auburn, Ala	78.1	74.0	86.8	82.7	69.4	65.4	98	1886	95	1887	53	1891	47	1888
Augusta, Ga	80.2	70.4	89.3	84.6	71.0	66.1	105	1878	98	1887	58	1888	41	1888
Batesville, Miss	79.0	73.6	89.9	84.3	68.2	63.0	102	1885	99	1884	49	1891	44	1889, 1891
Branchville, S. C	78.8	74.0	88.4	83.6	69.1	64.3	98	1887	95	1887	54	1888	35	1887
Brookhaven, Miss	79.7	75.6	91.5	88.0	68.0	63.3	99	1888, 1891	98	1889, 1891	47	1891	42	1889
Brownsville, Tex	83.1	79.7	91.3	87.6	74.9	71.9	101	1877, 1883	96	1877, 78, '79, '83, '84	64	1891	55	1890
Cedar Keys, Fla	81.8	79.5	87.9	86.1	75.6	72.9	96	1883	94	1881	69	1881, 86, '89	55	1888
Charleston, S. C	80.8	76.1	87.0	82.2	74.5	70.0	98	1887	94	1876	62	1879	50	1888
Cheraw, S. C	73.2	72.5	88.7	82.9	67.6	62.1	108	1887	102	1883	52	1885	52	1890
Chester, S. C	78.9	73.5	89.4	84.0	68.3	63.0	101	1886, 1887	101	1887	53	1887	37	1888
Chattanooga, Tenn	76.7	71.2	85.6	80.3	67.8	62.0	100	1881	96	1881	54	1891	38	1888
Columbus, Miss	81.1	75.6	94.0	88.4	68.2	62.9	107	1891	105	1887	51	1887, 1891	43	1887
Corinth, Miss	78.5	72.8	89.8	84.2	67.2	61.4	102	1888	98	1884	45	1884	38	1888
Coushatta, La	81.2	75.7	93.0	87.6	69.4	63.8	103	1883	98	1883, 1884	46	1891	44	1888
Charlotte, N. C	76.4	71.3	85.2	79.9	67.6	62.6	101	1881	94	1881, 1887	53	1887	38	1888
Devall Bluff, Ark	76.8	71.2	88.9	84.0	64.8	58.5	104	1884	100	1887	49	1891	38	1883, 1885
Edwards, Miss	81.4	76.5	91.5	87.3	71.3	65.6	99	1887	98	1884	51	1891	48	1889
El Paso, Tex	80.8	73.6	94.4	86.7	67.2	60.4	110.2	1884	104	1879	52	1880	42	1889
Fort Davis, Tex	73.8	68.2	83.3	79.6	62.3	56.8	100	1884	94	1883	47	1882	37	1883
Florence, S. C	79.2	73.5	89.6	83.7	68.7	63.2	101	1883	97	1883	54	1887	38	1887
Fort Elliott, Tex	76.2	69.4	87.8	81.9	64.6	56.9	104	1888	98	1881	48	1880, 1882	37	1880
Fort Smith, Ark	79.0	73.4	89.9	84.5	68.3	62.3	104	1886	99.9	1884	45	1891	39.6	1883
Galveston, Tex	83.5	79.3	88.7	84.1	78.2	74.4	98.5	1874	94	1875, 1876	68	1891	56	1890
Hardeeville, S. C	80.1	75.6	90.1	85.1	70.1	66.2	100	1883, '87, '88	98	1887	50	1888	42	1887
Hatteras, N. C	77.8	74.1	81.9	78.8	72.7	69.4	92	1881, 1883	90	1881	60	1879	50	1888
Hernando, Miss	77.6	72.4	89.1	83.9	66.1	60.9	103	1883, 1885	101	1883	47	1883	43	1886
Jackson, Miss	80.2	75.4	91.5	87.2	68.2	63.6	100	1884	99	1883	50	1891	44	1889
Jacksonboro, S. C	78.7	73.9	89.2	84.6	68.1	63.1	99	1887	98	1887	45	1887	36	1887
Jacksonville, Fla	81.7	78.3	89.7	85.6	73.7	71.0	100	1874	98	1875	64	1889, 1890	55	1887, 1888
Kingston, S. C	77.9	72.4	89.2	83.6	66.5	61.2	99	1883, 1888	98	1890	43	1886	34	1887
Kittyhawk, N. C	76.0	73.7	80.1	79.1	72.0	68.3	102	1888	97	1888	58	1888	39	1888
Knoxville, Tenn	75.4	69.9	85.0	79.9	65.8	59.8	100	1881	97	1881	50	1879	35	1888
Lake, Miss	78.9	74.9	90.7	86.5	67.2	63.4	100	1886	100	1887	46	1891	40	1889

Little Rock, Ark	79·1	73·3	88.1	82.2	70.0	64.4	102	1881	97	1881, 1887	52	1891	47	1881
Macon, Miss	79·9	75·1	91.8	88.3	67.9	61.8	102	1885	101	1883	50	1884	40	1885, '89, '90
Malvern, Ark	78.6	72.8	91.4	85.6	65.8	59.9	105	1883, 1885	100	1887	37	1887	30	1887
Memphis, Tenn	79·0	72.4	87.6	81.2	70.4	63.6	102	1874	99	1887	53	1891	44	1875
Mobile, Ala	80.7	74.8	88.2	85.7	73.2	63.9	100	1874	96	1881, 1887	57	1891	52	1888
Monroe, La	80.4	75.4	90.7	85.8	70.0	64.9	100	1886	97	1883, 1887	54	1891	46	1883
Montgomery, Ala	80.2	76.0	88.6	85.3	71.7	66.7	103	1874	99	1887	58	1891	46	1888
Nashville, Tenn	77.8	70.3	86.8	79.7	67.7	60.9	104	1874	99	1887	51	1891	38	1888
Natchitoches, La	79.7	74.6	90.5	84.3	69.0	64.9	98	1885, '88, '89	96	1889	46	1891	33	1883
New Orleans, La	81.8	78.5	88.2	84.8	75.4	72.1	96	1877	94	1887, 1889	63	1891	56	1888, 1890
Okolona, Miss	80.7	74.8	93.0	88.2	68.4	61.4	106	1885	104	1887	48	1891	32	1887
Palestine, Tex	81.3	75.5	91.3	85.2	71.3	65.9	100	1887	95·5	1883	62	1884, 1887	47	1890
Pensacola, Fla	80.9	77.7	87.6	84.6	74.2	70.9	96	1886	94	1884, 1887	62	1891	54	1888, '89, '90
Prescott, Ark	79.4	73.9	90.1	82.4	68.7	63.5	102	1883, '85, '86	96	1884, 1886	43	1884	38	1885
Rio Grande City, Tex	86.3	81.6	98.0	92.1	74.6	71.1	112	1877	107	1877	59	1881	52	1890
Savannah, Ga	79.1	76.0	87.8	82.9	70.4	69.0	100	1878	96	1876, 1877	63	1879, 1890	48	1888
San Antonio, Tex	82.6	77.2	93.2	86.7	72.0	67.7	108	1877	100	1877	57	1891	50	1887
Shreveport, La	82.4	75.7	92.4	85.2	72.3	66.2	105	1881	101	1881	54	1891	47	1881
Spartanburg, S. C	76.7	72.0	87.6	83.0	65.8	60.9	98	1883, 1885	97	1883	50	1887, 1890	36	1887
St. Matthews, S. C	79.2	73.9	88.2	83.6	70.1	64.1	100	1883, 1888	101	1887	56	1886	39	1887
St. Georges, S. C	75.9	73.8	89.6	84.3	68.2	63.4	100	1886, 1888	96	1886	54	1888	38	1888
Texarkana, Ark	80.1	75.5	92.5	88.5	67.7	62.5	111	1886	99	1886, 1887	40	1886	44	1886
Vicksburg, Miss	80.9	75.4	90.2	84.3	71.6	66.4	100	1878	98	1881	54	1891	48	1871
Wilmington, N. C	78.4	73.5	85.9	81.1	70.9	65.8	99	1878	96	1872	56	1874, 1887	42	1887

Table XXII, temperatures for the months of August and September, is furnished at this place to show how uniform the climate is during the flowering and fiber-developing periods of the cotton. The normal temperature for the month of August is but little different from that given for June and July, and the temperature for September is but a few degrees lower. Thus we see we have four months of practically uniform climate, so far as heat is concerned, and these results are all the more interesting when taken in connection with plant growth. At this season of the year, when buds are being formed and the fruit is developing with all its tender functions, uniform degrees of heat are absolutely demanded. This is particularly true in regard to the cotton plant, when it is well known that any sudden changes in the atmospheric conditions will cause the squares to shed, the leaves to drop off, and even young bolls to die, and thus greatly reduce the yield of the crop.

The more one studies this important question of the effects of climatic changes on plant economy the more he becomes convinced that an All-wise Husbandman has specially prepared this Southern land for the cultivation of the valuable staple with which the nations of the earth are clothed.

TABLE XXIII.—*Normal data for monthly precipitation during autumn, at stations in the cotton-belt region.*

Stations.	Precipitation for September.	Precipitation for October.	Precipitation for November.	Autumn precipitation.
	Inches.	*Inches.*	*Inches.*	*Inches.*
Charlotte, N. C	3.24	3.65	3.09	9.98
Hatteras, N. C	6.61	6.52	5.32	18.45
Kittyhawk, N. C	5.18	4.08	4.16	13.42
Wilmington, N. C	6.70	4.09	2.55	13.34
Charleston, S. C	6.06	4.36	3.19	13.61
Atlanta, Ga	4.21	2.88	3.97	11.06
Augusta, Ga	3.74	2.65	3.19	8.58
Savannah, Ga	5.89	3.73	2.18	11.80
Cedar Keys, Fla	5.37	2.81	2.67	10.85
Jacksonville, Fla	8.06	5.62	2.56	16.24
Pensacola, Fla	5.25	3.46	4.34	13.05
Chattanooga, Tenn	4.24	3.10	4.33	11.67
Knoxville, Tenn	3.06	3.08	4.08	10.22
Memphis, Tenn	3.23	3.13	4.80	11.16
Nashville, Tenn	3.83	2.65	4.05	10.53
Auburn, Ala	3.29	2.48	4.49	10.26
Mobile, Ala	5.06	2.89	4.31	12.26
Montgomery, Ala	3.11	2.54	3.53	9.18
Vicksburg, Miss	3.85	2.89	5.10	11.84
Little Rock, Ark	3.23	2.48	5.53	11.24
Fort Smith, Ark	3.61	2.84	4.06	10.51
New Orleans, La	4.82	3.37	4.40	12.59
Shreveport, La	4.25	3.36	4.84	12.45
Brownsville, Tex	7.73	3.90	2.11	13.74
El Paso, Tex	1.22	1.15	0.55	2.92
Fort Davis, Tex	2.90	1.65	0.56	5.13
Fort Elliott, Tex	1.77	2.64	0.59	6.00
Galveston, Tex	7.07	4.77	4.56	16.40
Indianola, Tex	7.01	3.71	3.06	13.78
Palestine, Tex	3.21	3.44	4.53	11.18
Rio Grande City, Tex	3.78	2.22	0.89	6.89
San Antonio, Tex	4.16	1.82	2.00	7.98
Corsicana, Tex	3.09	2.35	3.44	8.88

Table XXIII, precipitation at stations over the cotton region, shows remarkably uniform results at all points, with the exception of some stations located in the western part of Texas and on the Atlantic and Gulf coasts. The experience of the writer, extending over a number of years of practical observation of changes of the weather and on the cultivation of the cotton, has convinced him that autumn is not a wet period in the South, and that floods during this season of the year are very rare. It is therefore particularly a suitable time for the white, delicate fiber of the cotton to protrude beyond the carpels of the bolls, and not run the risk of becoming stained by continued precipitation or a long period of cloudy weather.

At the beginning of October, under the influence of cool nights, with the general reduction of temperature during the day, the bolls have about all matured that will produce good grades of cotton. It is not often that undergrown bolls, the latter part of October, will develop good fiber unless the season of mild weather is unusually prolonged into December. This condition of the climate has occurred several times within the past twenty or twenty-five years, and the cotton crops those years were very large.

Table XXIV, temperatures for October and November, shows uniform reduction in the normals of 10° to 12° from those given in the table for August and September, but at no place throughout the belt, excepting at extreme northern points, is the reduction in October so great as to endanger the life of the plant. This statement is true where normals are concerned, but when we examine the records year after year we will find it necessary to modify our assertion somewhat. At nearly all stations north of Augusta, Ga., and Montgomery, Ala., some years give several days in October that produce frosts. For instance, at Augusta, Ga., the thermometer reached below 35° four Octobers in a period of nineteen years. But the minimum temperature during this time reached the frost point only twice, viz., in 1873 and in 1891. In the case of the mean minimum temperature we find that fifteen years gave results above 50°. In the case of Charleston, S. C., not much farther south, only once during the twenty years of record did the temperature go below 40°, and that was in 1873, when the thermometer registered 39°; ten years it was 45° and above; the mean minimum ranged between 55° and 66°. To bring this case out more clearly let us take one more station, viz., Vicksburg, Miss., a town in the west and some distance inland. Here the minimum temperature reached below 35°, but above 30°, only once during a period of nineteen years, this was in 1873, when the thermometer recorded as low as 31°. The remaining eighteen years the minimum temperature was above 38°. At no time did the mean minimum temperature fall below 50°.

According to charts very carefully made from the records of 100 stations over the Southern States, the normal time of frost for October 15 passes as far north as Kittyhawk, Charlotte, Chattanooga, Nashville, Cairo, Dodge City, and Fort Elliott. While the frost line for November passes through Charleston, Atlanta, Starksville, Vicksburg, and Palestine. We may safely assert, therefore, that usually there will be good picking season, as far as the temperature is concerned, until November 1. At intervals in the South the season favorable for gathering the crop extends far into the winter, and one year, in the recollection of the writer, the planters were picking as late as the middle of December. These occasions, however, are rare, and it is almost universally the case that the heavy frosts in November put a stop to all cotton picking.

VIII.—COMMENTS ON YEARS OF GOOD AND POOR CROPS.

As a conclusion to the subject of the climatology of the cotton plant I have prepared Table XXV, showing yield of cotton in each state, with the climatic conditions. Two years, 1878 and 1879, are years of good crops, and the other two years, 1884 and 1886, are years of small and poor crops. If the season has been unpropitious in the quantity of rain during the months of May and June, and part of July, and a season of rains, with a good per cent. of sunshine, should continue through August, a fine crop may be assured, provided September and October are dry. But if June, July, and August are very dry and hot, and September and October are wet, the crop will be greatly cut off.

At the close of the years 1878 and 1879 the farmers in the South gathered large crops of cotton in an average fair condition. An analysis of the table will satisfactorily explain the reasons for these large yields. In 1878 the rains in June and July were not excessive, except in Alabama, Mississippi, and Louisiana. In August the deficiency of June and July was brought up, and in September and October, during the picking season, the weather was generally dry. The season for maturing the fiber and picking was excellent. The rains in Alabama, Mississippi, and Louisiana encouraged the multiplication of insects and rust so that the average yield per acre was materially cut off in those States. The percentage of clear days was large throughout the year, and although moisture was amply sufficient for the growing crop, the sunshine was materially beneficial in opening the bolls and drying out the fiber. With the exception of June the temperature was high—several degrees above the normal—thus adding another important factor to the advantage of the cotton. The crop was larger than the great one of 1877.

The spring and summer of 1879 were not so favorable as they were in 1878, because of the general deficiency of rain in June, and the low temperature in June, August, and September. The drought in the spring and nearly half of the summer prevailed over the entire South. The timely rains that came the latter part of July and continued through August encouraged a rapid development in the growth of the plant; and the few rainy days with the large percentage of clear days in September and October caused the fruit to ripen rapidly, and the increasing warmth of October caused the bolls to open and prevented staining and decaying of the fiber. The excellent season for picking extended into December and thus greatly increased the yield of the crop.

There were great spring floods throughout the South in 1884, and also in 1886, and the crops were badly damaged by the heavy rains with the small percentage of sunshine during the month of June. The temperature was also generally below the normal throughout the entire summer. The plant was thus greatly retarded in its growth and a large loss was sustained in the shedding of the forms and the rotting of the bolls. The autumn in each year was more favorable than was the weather in spring and summer, and this seasonable condition did much to make amends for the disasters in spring and summer. The fiber was gathered in 1886 in an unstained condition and there was a minimum amount of dirt and trash in the cotton gathered. The maturing season was so unfavorable the vitality of the plant was greatly reduced, and but for the excellent soils and good tillage in some portions of the belt the cotton crops for the years 1884 and 1886 would have been much smaller than reported.

IX.—DISCUSSION OF TEMPERATURE CHARTS.

These charts have been prepared for this work to bring out more clearly the fact already referred to several times in these pages, viz., the summer temperature is very uniform throughout the cotton belt.

In preparing the charts the stations in extreme western and southwestern Texas have been omitted because they are outside of what has been assumed as the cotton region. The high maxima in July, recorded for the middle section of the belt, are unusual extremes that occurred at only one station in 1881, Montgomery, Ala., and at one station in 1887, Kittyhawk, N. C., within periods of nineteen and seventeen years. In 1881, at all stations the maxima were 92°, 96°, 102°, 103°, 100°, and 105°. In 1887 the maxima were 104°, 95°, 98°, 104°, 100°, 89°, 100°, and 102°.

These charts are of special interest in showing clearly the uniform temperature for the three months of summer. In June the mean temperature ranges between 81° and 76°, in July between 83° and 78.5°, and in August between 81.5° and 78.5°.

These charts also bring out the other important fact, already mentioned in this work, that the mean maxima and mean minima are never great extremes, and may be repeated from year to year while the highest range of maximum may occur only once in a period of ten years. It is proper, therefore, to carefully study these mean maxima and mean minima in connection with the study of plant growth, rather than lay special stress on low and high extremes that occur so seldom in such long periods of years. In the southern section of the cotton belt the mean maximum, during the twelve years under consideration, varied only 4° in June, 4° in July, and 3° in August. The mean minimum for June varied only 3.5°; for July, 3°, and for August, 3°.

During the winter months these two factors give much greater variations, for reasons that are not necessary to discuss in this work

Table XXIV.—*Temperature for months of October and November.*

Stations.	Monthly mean.		Mean maximum.		Mean minimum.		Maximum.				Minimum.			
							October.		November.		October.		November.	
	October.	November.	October.	November.	October.	November.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.
	°	°	°	°	°	°								
Aberdeen, Miss	62.0	....	74.0	....	50.0	....	95	1883	....	....	26	1890	....	....
Allendale, S. C	65.6	....	76.5	....	54.7	....	95	1884	....	....	30	1884	....	....
Atlanta, Ga	62.0	51.9	70.5	60.4	53.6	43.4	91	1884	82	1890	30	1887	16	1887
Auburn, Ala	64.0	53.8	74.7	63.8	53.4	43.7	94	1884	81	1882	31	1891	12	1891
Augusta, Ga	64.8	55	75.2	65.4	54.4	44.6	94	1884	85	1885	29	1873	24	1873, '87, '89
Batesville, Miss	62.2	....	74.4	....	50.1	....	97	1884	....	....	28	1884	....	....
Branchville, S. C	63.4	....	74.8	....	52.0	....	95	1884	....	....	30	1891	....	....
Brookhaven, Miss	68.4	....	79.3	....	52.5	....	95	1883, '84	....	....	28	1886, '87	....	....
Brownsville, Tex	70.1	66.8	83.8	74.9	66.4	58.6	95	1877	89	1882	49	1879, '89	30	1880
Cedar Keys, Fla	72.6	63.5	79.2	70.6	66	56.4	89	1881, '84	81	1881, '82, '86	39	1887	27	1887
Charleston, S. C	67.2	58.3	74.1	65.6	60.2	50.9	93	1883	82	1879	39	1873	28	1873, '81, '87
Cheraw, S. C	61.9	....	74.2	....	49.6	....	96	1884	....	....	28	1891	....	....
Chester, S. C	62.7	....	74.1	....	51.3	....	95	1884	....	....	30	1887, '89, '91	....	....
Chattanooga, Tenn	61.6	50.5	71.1	59.6	52.1	41.4	91	1884	79	1879, '90	32	1889	16	1889
Columbus, Miss	64.5	....	77.5	....	55.1	....	98	1883	....	....	30	1884	....	....
Corinth, Miss	62.6	....	75.4	....	49.9	....	97	1884	....	....	22	1884	....	....
Coushatta, La	65.0	....	77.9	....	52.0	....	94	1883	....	....	28	1887	....	....
Charlotte, N. C	64.6	50.7	71.3	60	51.8	41.4	92	1884	80	1879	30	1879	18	1880
Devall Bluff, Ark	61.5	....	75.9	....	47.2	....	92	1884	....	....	20	1889	....	....
Edwards, Miss	65.8	....	77.0	....	54.5	....	94	1883, '84	....	....	31	1887	....	....
El Paso, Tex	63.8	51.2	78.2	64.9	49.4	37.6	94	1879, '87	82	1882	28	1882	11	1880
Fort Davis, Tex	61.9	50.6	74.0	62.8	49.7	38.3	90	1881	82	1885	30	1880	6	1880
Fort Elliott, Tex	58.1	43.5	70.3	56.3	45.9	30.8	94	1889	84	1888	25	1887	— 5	1880, '87
Fort Smith, Ark	62.8	50.6	74.5	61.4	51.1	39.8	94.6	1884	86	1882	31	1886	19	1891
Galveston, Tex	72.6	62.3	77.6	67.6	67.5	57	89	1890	85	1886	45	1873	29	1880
Hardeeville, S. C	65.9	....	77.1	....	54.8	....	96	1884	....	....	30	1884	....	....
Hatteras, N. C	65.1	56.1	70.2	61.7	60	50.4	90	1881	79	1882	42	1876, '80, '87	28	1879
Hernando, Miss	61.4	....	73.3	....	49.6	....	97	1884	....	....	24	1886	....	....
Jackson, Miss	65.2	....	77.3	....	53.2	....	97	1883	....	....	30	1891	....	....
Jacksonboro, S. C	69.5	....	75.9	....	53.0	....	99	1884	....	....	27	1886	....	....
Jacksonville, Fla	70.5	62.5	78.3	71.1	62.8	53.8	92	1883, '84	86	1889	40	1873, '87	26	1887
Kingstree, S. C	62.7	....	75.3	....	50.1	....	....	....	....	....	....	....	....	....
Kittyhawk, N. C	64.1	53.9	69.6	59.9	58.6	47.9	90	1881	80	1888	38	1876	23	1879
Knoxville, Tenn	58.8	47.8	69.5	57.4	48.1	38.2	94	1884	81	1881	25	1876	12	1872
Lake, Miss	63.5	....	76.5	....	50.5	....	98	1883	....	....	28	1884, '91	....	....
Little Rock, Ark	63.7	51.3	73	60.1	54.3	42.5	90	1881, '83	83	1882	33	1886, '87	0	1887
Macon, Miss	64.3	....	77.6	....	51.0	....	99	1883	....	....	28	1887	....	....
Malvern, Ark	69.6	....	85.9	....	53.7	....	94	1883	....	....	27	1885	....	....

TABLE XXIV.—*Temperature for months of October and November*—Continued.

Stations.	Monthly mean.		Mean maximum.		Mean minimum.		Maximum.				Minimum.			
	October.	November.	October.	November.	October.	November.	October.		November.		October.		November.	
							Degrees.	Year.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.
	°	°	°	°	°	°								
Memphis, Tenn	62·7	50·9	71·3	59	54	42·8	92	1879, '84	82	1879	29	1878	16	1877, '80
Mobile, Ala	68.2	58·5	77	67·4	59·3	49·6	93	1884	83	1888	34	1873, '87	25	1887
Monroe, La	65·2	....	76·6	....	53·8	....	93	1883	....	....	32	1886	....	....
Montgomery, Ala	65·5	55·6	75·5	65·3	55·6	45·9	96	1884	83	1879, '82	32	1887	21	1872
Nashville, Tenn	60·3	48·8	70·3	57·8	50·3	39·8	92	1884	81	1882	27	1887	10	1887
Natchitoches, La	64·5	....	76·9	....	52·1	....	95	1883	....	....	32	1886, '91	....	....
New Orleans, La	70·4	61·0	77·3	68·1	63·4	53·9	90	1884, '89	85	1885, '88	40	1873	30	1891
Okolona, Miss	63·6	....	77·4	....	49·8	....	99	1883	....	....	27	1884	....	....
Palestine, Tex	66·8	56·5	77·1	66·1	56·4	46·9	94	1883	87	1888	37	1888	20	1887
Pensacola, Fla	67·8	59·4	75·6	67·6	62·1	51·2	95	1884	81	1882, '88	38	1887	28	1881, '87
Prescott, Ark	62·2	....	73·8	....	50·5	....	92	1884	....	....	23	1884	....	....
Rio Grande City, Tex	74·5	64·9	85·2	74·9	63·7	54·9	105	1877	98	1877	41	1891	30	1880, '83
Savannah, Ga	66·9	58·6	74·7	67·3	59·1	49·9	92	1883, '84	83	1889	37	1873	22	1872
San Antonio, Tex	69·5	58·3	80·1	68·6	58·9	48·1	99	1877	88	1879, '91	40	1888	21	1880
Shreveport, La	66·4	55·6	76·6	65·4	56·2	45·7	95	1883	86	1882	31	1873	18	1880
Spartanburg, S. C	60·4	....	73·5	....	47·3	....	96	1884	....	....	22	1889	....	....
Saint Matthews, S.C	64·2	....	76	....	52·4	....	97	1884	....	....	33	1885	....	....
Saint Georges, S. C	63·9	....	75·6	....	52·1	....	97	1884	....	....	27	1884	....	....
Texarkana, Ark	63·6	....	78·3	....	48·8	....	91	1884	....	....	28	1891	....	....
Vicksburg, Miss	65·9	56·0	75·2	65·4	56·5	46·7	93·7	1884	85	1885, '89	34	1873, '87	22	1891
Waynesboro, Miss	64·9	....	78·2	....	51·5	....	90	1884	....	....	30	1886, '87	....	....
Wilmington, N.C	62·1	55·6	69·1	64·7	55·1	46·5	93	1884	83	1877	32	1876	20	1872

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, with the climatic conditions controlling the yield of cotton in each State of the cotton belt.*

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1878.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	3.81	−0.97	71.1	−4.3	36	43	57	3.27	−2.74	79.3	+0.5	24	32	68	8.24	+1.83	78.4	+1.2	56	49	51
South Carolina	4.44	−0.33	......	......	37	50	50	8.98	+3.18	......	......	55	42	58	8.10	+2.14	......	......	42	45	55
Georgia	5.20	−0.04	78.2	0.0	45	57	43	6.11	+1.62	83.7	+2.7	40	45	55	6.05	+0.55	83.8	+5.3	42	52	48
Florida	......	......	......	......	38	......	......	......	......	......	......	53	......	......	......	......	......	......	45	......	......
Alabama	6.15	+1.35	79.2	+1.4	37	53	47	3.31	−1.06	84.2	+0.3	37	52	48	7.82	+3.82	82.4	+3.5	44	45	55
Tennessee	4.62	−0.23	73.3	−2.7	43	50	50	5.73	+1.51	82.4	+3.2	40	39	61	4.53	+0.98	80.0	+2.8	34	39	61
Mississippi	7.21	+2.06	78.9	+0.1	50	50	50	3.99	−0.63	83.7	+2.4	23	36	64	4.47	+0.56	82.6	+2.4	42	39	61
Louisiana	7.50	+2.59	80.3	−0.5	45	49	53	6.16	+0.90	83.8	+0.5	48	39	64	3.80	−0.03	80.2	−1.9	48	36	64
Texas	2.43	−0.75	83.3	+2.6	33	......	......	6.79	+3.99	83.9	+0.7	30	......	......	6.34	+3.09	84.1	+1.9	40	......	......

States.	September.							October.							Injury to crop from insects, etc.	Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.			
1878.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°						
North Carolina	4.06	−1.18	74.4	−1.5	42	40	60	7.91	+3.61	63.5	−0.2	26	39	61	Small	0.38	221,699
South Carolina	8.56	+3.69	......	......	33	57	43	2.69	−0.76	......	......	23	42	58	...do	0.36	342,173
Georgia	8.02	+4.27	75.5	+3.0	38	57	43	1.97	−0.79	66.1	+1.5	25	39	61	Bad in sections.	0.36	530,763
Florida	......	......	......	......	63	......	......	......	......	......	......	26	......	......	......	0.24	39,256
Alabama	2.64	−0.10	76.3	−3.6	20	43	57	3.16	+0.69	65.6	+0.8	21	45	55	Bad in sections.	0.29	539,015
Tennessee	1.53	−1.62	70.1	−0.9	19	30	70	3.49	+0.60	61.8	+1.6	29	33	67	Small	0.59	430,190
Mississippi	2.46	−1.65	75.8	+0.4	......	37	63	3.90	+0.83	66.0	−0.3	29	36	64	Bad in sections.	0.30	748,952
Louisiana	2.15	−2.28	76.5	−0.6	32	33	67	3.37	−0.03	68.1	−0.3	29	33	67	...do	0.35	498,851
Arkansas	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.61	707,282
Texas	4.76	−0.96	78.9	−1.8	22	......	......	1.71	−2.14	73.9	+2.0	21	......	......	Small	0.61	1,105,133
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5,169,314

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, &c.*—Continued.

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1879.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	2.37	−2.41	73.4	−2.0	28	33	67	5.54	−0.47	78.1	−0.7	34	45	55	8.02	+1.61	75.7	−1.5	51	49	51
South Carolina	2.58	−2.19	.....	.....	23	40	60	7.63	+1.83	.....	.....	26	42	58	5.71	−0.25	.....	.....	39	55	45
Georgia	3.42	−1.82	77.8	−0.2	21	43	57	5.51	+0.52	82.1	+0.9	31	42	58	4.87	−0.63	77.4	−1.1	36	61	39
Florida	.....	.....	.....	.....	37	.....	.....	.....	.....	.....	.....	40	.....	.....	.....	.....	.....	.....	48	.....	.....
Alabama	2.97	−1.83	75.9	−1.9	43	40	60	5.10	+0.70	81.1	−2.8	55	52	48	4.93	+0.92	75.6	−3.3	47	48	52
Tennessee	2.55	−2.30	75.8	−0.2	28	43	57	4.92	+0.70	82.0	+2.8	37	45	55	4.03	+0.42	74.4	−2.8	31	45	55
Mississippi	2.96	−2.19	78.9	+0.1	27	37	63	4.36	−0.26	83.2	+1.9	29	45	55	6.50	+2.59	77.9	−2.3	39	45	55
Louisiana	2.53	−2.38	80.7	−0.1	22	33	67	4.73	−0.53	83.8	+0.5	34	45	55	7.60	+3.77	80.0	−2.1	18	42	58
Arkansas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	23	.....	.....	.....	.....	.....	.....	32	.....	.....
Texas	2.28	−0.90	79.4	−1.3	23	.....	.....	1.60	−1.20	84.9	+1.7	19	.....	.....	6.91	+3.66	81.9	−0.3	23	.....	.....

States.	September.							October.							Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.		
1879.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°					
North Carolina	5.68	+0.44	70.0	−5.9	28	40	60	2.79	−1.51	66.8	+3.1	23	45	55	0.35	216,978
South Carolina	3.63	−1.24	.....	.....	30	37	63	3.48	+0.03	.....	.....	35	52	48	0.32	300,173
Georgia	3.81	+0.06	72.2	−0.3	16	40	60	4.02	+1.26	67.9	+3.3	35	61	39	0.35	551,893
Florida	.....	.....	.....	.....	66	.....	.....	.....	.....	.....	.....	58	.....	.....	0.23	37,707
Alabama	1.44	−1.30	70.9	−9.0	23	30	70	6.65	+4.18	66.4	+1.6	47	58	42	0.38	715,020
Tennessee	2.01	−1.14	68.4	−2.6	18	22	78	2.48	−0.41	65.1	+1.7	27	39	61	0.59	454,349
Mississippi	2.89	−1.22	74.0	−1.4	17	30	70	1.35	−1.78	68.7	+2.4	16	35	64	0.41	849,400
Louisiana	2.05	−2.38	76.6	−0.5	15	30	70	0.94	−2.46	70.4	+2.0	24	42	58	0.45	593,431
Arkansas	.....	.....	.....	.....	3	.....	.....	.....	.....	.....	.....	16	.....	.....	0.61	719,583
Texas	6.34	+0.62	78.7	+1.6	18	.....	.....	2.19	−1.66	72.2	+0.3	19	.....	.....	0.39	752,500
Total	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5,191,034

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, &c.*—Continued.

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1884.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	6.12	+1.34	71.8	-2.6	40	50	50	9.37	+3.36	78.0	-0.8	47	45	55	6.03	-0.38	76.1	-1.1	35.	52	48
South Carolina	6.72	+1.95	74.2	-3.8	50	67	33	6.34	+0.54	80.8	-1.4	36	45	55	8.09	+2.13	78.1	+0.3	48	45	55
Georgia	8.15	+2.91	78.0	-0.2	50	60	40	3.12	-1.37	80.4	-0.6	32	39	61	4.74	-0.76	77.6	-0.9	38	39	61
Florida	7.14	+1.38	77.2	-3.0	50	......	......	6.94	+1.70	82.0	-0.1	55	......	......	5.13	-1.12	80.4	-1.1	54	......	......
Alabama	8.82	+4.02	74.6	-3.2	57	57	43	4.18	-0.22	79.4	-4.5	44	42	58	2.25	-1.76	77.2	-1.7	23	36	64
Tennessee	6.37	+1.52	73.0	-3.0	57	60	40	4.72	+0.50	77.8	-1.4	48	49	51	2.94	-0.67	75.2	-2.0	23	39	61
Mississippi	4.92	-0.23	77.4	-1.4	47	45	55	4.78	+0.16	83.4	+2.1	27	36	64	1.31	-2.60	79.8	-0.4	16	29	71
Louisiana	6.41	+1.50	79.4	-1.4	47	43	57	2.09	-3.15	85.8	+2.5	23	36	64	1.43	-2.40	81.5	-0.6	19	33	67
Arkansas	2.30	-2.03	75.6	0.0	20	......	......	5.11	+1.12	81.5	+0.8	29	......	......	3.50	-0.29	76.8	-2.0	24	......	......
Texas	4.77	+1.59	77.6	-3.1	22	......	......	0.69	-2.11	82.8	-0.4	6	......	......	2.23	-1.02	81.0	-1.2	13	......	......

States.	September.							October.							Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.		
1884.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°					
North Carolina	3.52	-1.72	74.5	-1.4	13	30	70	1.15	-3.15	67.3	+3.6	13	29	71	0.38	398,200
South Carolina	4.40	-0.47	74.7	+2.1	16	33	67	0.12	-3.33	68.9	+3.4	13	23	77	0.29	469,600
Georgia	2.96	-0.79	75.9	+3.4	20	23	77	1.27	-1.49	69.7	+5.1	12	20	80	0.26	752,500
Florida	4.71	-2.65	79.2	+0.7	32	......	......	2.23	-3.60	73.6	+3.3	17	......	......	0.23	58,900
Alabama	1.45	-1.29	75.2	-4.7	12	23	77	3.02	+0.55	69.5	+4.7	15	22	78	0.24	630,400
Tennessee	2.44	-0.71	74.2	+3.2	18	40	60	2.44	-0.45	65.6	+2.2	16	29	71	0.38	310,700
Mississippi	2.50	-1.61	78.8	+3.4	28	33	67	0.99	-2.14	70.0	+3.7	23	29	71	0.40	901,300
Louisiana	2.61	-1.82	80.5	+3.4	27	30	70	3.07	-0.33	71.2	+2.8	24	33	67	0.53	490,200
Arkansas	5.02	+1.66	77.0	+3.6	30	......	......	1.31	-1.51	64.9	+1.0	11	......	......	0.44	518,500
Texas	5.21	-0.21	79.1	+2.0	32	......	......	7.52	+3.67	68.6	-3.3	36	......	......	0.37	1,118,000
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5,648,300

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, &c.*—Continued.

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1886.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	8.58	+3.80	72.7	−2.7	53	60	40	9.86	+3.85	77.1	−1.7	42	45	55	6.95	+0.54	75.6	−1.6	50	58	42
South Carolina	10.16	+5.39	77.1	−0.9	57	67	33	6.02	+1.22	79.8	−2.4	42	48	52	1.42	−4.54	78.8	+1.0	36	55	45
Georgia	8.52	+3.28	78.4	+0.2	50	60	40	5.54	+1.05	78.1	−2.9	45	42	58	4.02	−1.48	77.9	−0.6	36	48	52
Florida	6.75	+0.99	80.5	+0.3	47	......	......	11.85	+6.67	80.5	−1.6	71	......	......	7.38	+1.13	80.7	−0.8	45	......	......
Alabama	5.56	+0.76	75.8	−2.0	60	60	40	3.68	−0.72	77.6	−6.3	39	39	61	3.38	−0.63	78.6	−0.3	36	45	55
Tennessee	6.79	+1.94	72.7	−3.3	48	63	37	4.56	+0.34	76.4	−2.8	29	33	67	5.72	+2.11	76.2	−1.0	40	51	49
Mississippi	9.50	+4.35	76.8	−2.0	60	53	47	2.37	−2.25	79.9	−1.4	33	33	67	3.22	−0.69	80.2	0.0	37	36	64
Louisiana	6.73	+1.82	78.7	−2.1	55	53	47	3.47	−1.79	80.7	−2.6	45	39	61	3.00	−0.83	81.7	−0.4	29	22	78
Arkansas	7.69	+3.36	74.2	−1.4	50	......	......	2.80	−1.19	79.4	−1.3	36	......	......	3.57	−0.22	79.1	+0.4	26	......	......
Texas	4.66	+1.48	77.8	−2.9	30	......	......	2.46	−0.34	80.8	−2.4	39	......	......	2.75	−0.50	81.1	−1.1	20	......	......

States.	September.							October.								
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Bales per acre.	Total number of bales.
1886.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°					
North Carolina	2.01	−3.23	73.6	−2.3	16	40	60	0.45	−3.85	63.4	−0.3	1	23	77	0.38	407,230
South Carolina	2.06	−2.81	75.3	+2.7	20	40	60	0.59	−2.86	62.5	−3.0	1	23	77	0.32	554,652
Georgia	0.94	−2.81	74.9	+2.4	20	37	63	0.36	−2.40	63.4	−0.2	13	21	79	0.32	960,025
Florida	2.53	−4.83	79.0	+0.5	37	......	......	1.73	−4.10	69.7	−0.6	19	......	......	0.27	73,837
Alabama	1.44	−1.30	75.5	−4.4	13	37	63	0.36	−2.11	64.3	−0.5	3	22	78	0.27	760,447
Tennessee	3.92	+0.77	71.6	+0.6	23	37	63	0.66	−2.23	59.6	−3.8	13	22	78	0.37	321,638
Mississippi	5.52	+1.41	76.0	+0.6	37	40	60	0.48	−2.65	65.7	−0.6	10	19	81	0.40	1,019,470
Louisiana	4.54	+0.11	77.4	+0.3	39	40	60	1.91	−1.49	67.1	−1.3	10	19	81	0.49	487,722
Arkansas	5.23	+1.87	73.8	+0.5	30	......	......	1.30	−1.52	61.6	−2.3	13	......	......	0.45	610,666
Texas	13.78	+8.06	77.9	+0.8	50	......	......	2.02	−1.83	67.3	−4.6	13	......	......	0.38	1,332,027
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	6,527,714

CHART I.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the winter months along the northern limits of the cotton belt.*

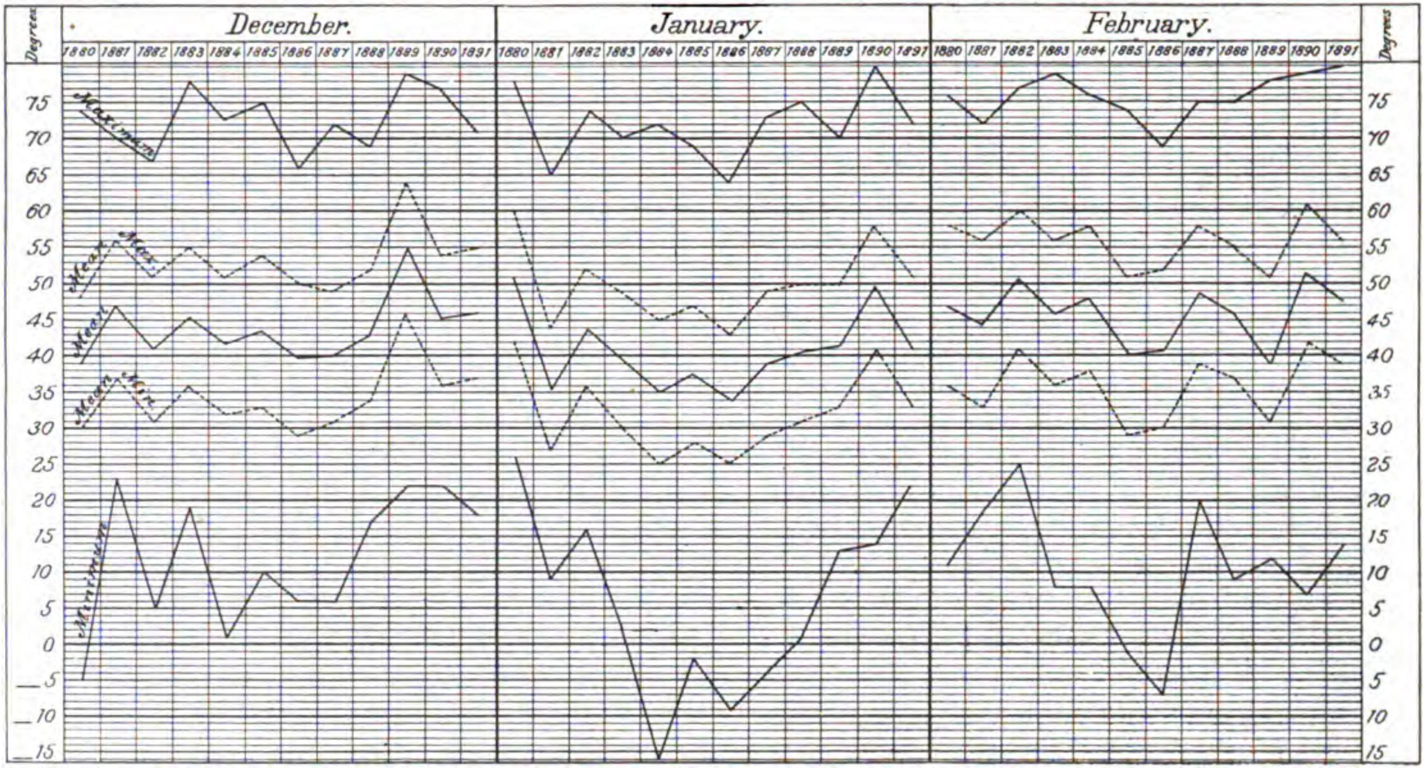


CHART II.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the summer months along the northern portions of the cotton belt.*

Chart III.—***Mean temperature, mean maximum, mean minimum, maximum and minimum for the winter months along the middle portions of the cotton belt.***

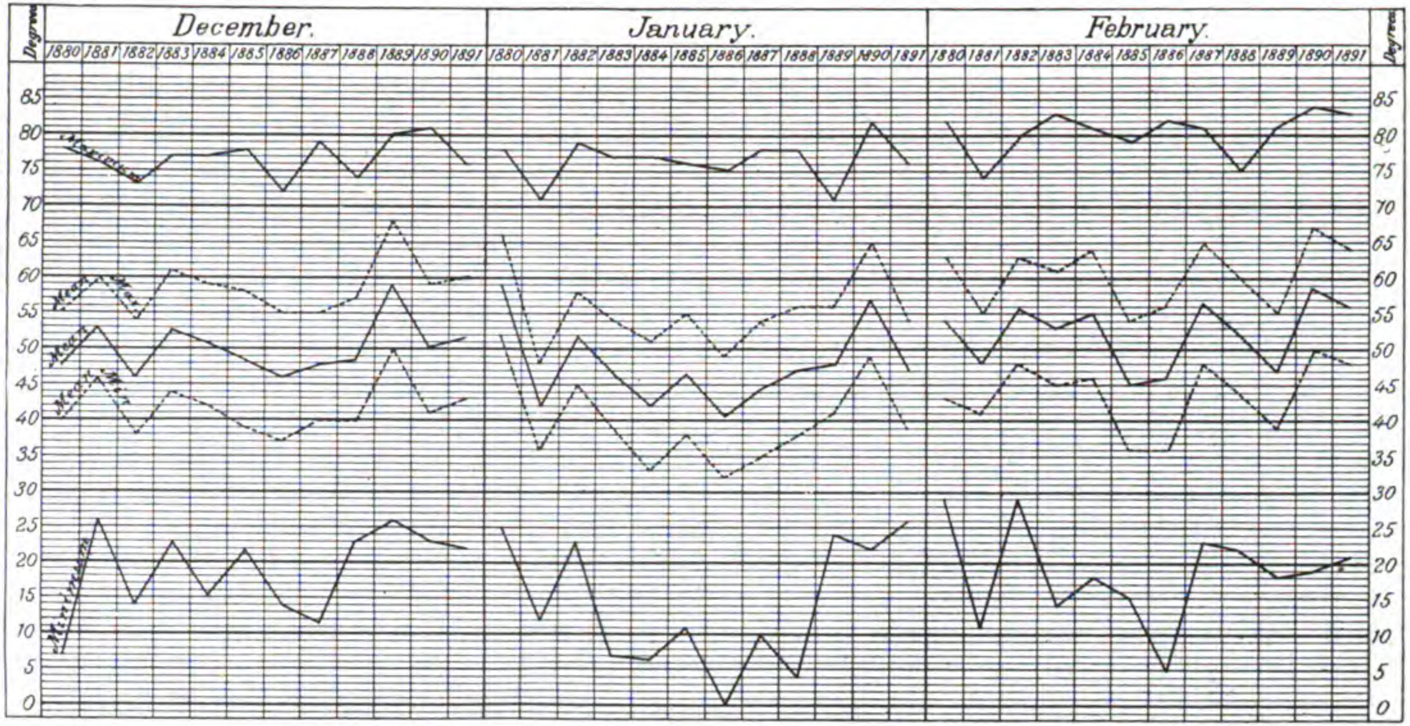


TABLE XXIV.—*Temperature for months of October and November*—Continued.

Stations.	Monthly mean.		Mean maximum.		Mean minimum.		Maximum.				Minimum.			
							October.		November.		October.		November.	
	October.	November.	October.	November.	October.	November.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.	Degrees.	Year.
	°	°	°	°	°	°								
Memphis, Tenn	62.7	50.9	71.3	59	54	42.8	92	1879, '84	82	1879	29	1878	16	1877, '80
Mobile, Ala	68.2	58.5	77	67.4	59.3	49.6	93	1884	83	1888	34	1873, '87	25	1887
Monroe, La	65.2	....	76.6	....	53.8	....	93	1883	....	....	32	1886	....	....
Montgomery, Ala	65.5	55.6	75.5	65.3	55.6	45.9	96	1884	83	1879, '82	32	1887	21	1872
Nashville, Tenn	60.3	48.8	70.3	57.8	50.3	39.8	92	1884	81	1882	27	1887	10	1887
Natchitoches, La	64.5	....	76.9	....	52.1	....	95	1883	....	....	32	1886, '91	....	....
New Orleans, La	70.4	61.0	77.3	68.1	63.4	53.9	90	1884, '89	85	1885, '88	40	1873	30	1891
Okolona, Miss	63.6	....	77.4	....	49.8	....	99	1883	....	....	27	1884	....	....
Palestine, Tex	60.8	56.5	77.1	66.1	56.4	46.9	94	1883	87	1888	37	1888	20	1887
Pensacola, Fla	67.8	59.4	75.6	67.6	62.1	51.2	95	1884	81	1882, '88	38	1887	28	1881, '87
Prescott, Ark	62.2	....	73.8	....	50.5	....	92	1884	....	....	23	1884	....	....
Rio Grande City, Tex	74.5	64.9	85.2	74.9	63.7	54.9	105	1877	98	1877	41	1891	30	1880, '83
Savannah, Ga	66.9	58.6	74.7	67.3	59.1	49.9	92	1883, '84	83	1889	37	1873	22	1872
San Antonio, Tex	69.5	58.3	80.1	68.6	58.9	48.1	99	1877	88	1879, '91	40	1888	21	1880
Shreveport, La	66.4	55.6	76.6	65.4	56.2	45.7	95	1883	86	1882	31	1873	18	1880
Spartanburg, S. C	60.4	....	73.5	....	47.3	....	96	1884	....	....	22	1889	....	....
Saint Matthews, S.C	64.2	....	76	....	52.4	....	97	1884	....	....	33	1885	....	....
Saint Georges, S. C	63.9	....	75.6	....	52.1	....	97	1884	....	....	27	1884	....	....
Texarkana, Ark	63.6	....	78.3	....	48.8	....	91	1884	....	....	28	1891	....	....
Vicksburg, Miss	65.9	56.0	75.2	65.4	56.5	46.7	93.7	1884	85	1885, '89	34	1873, '87	22	1891
Waynesboro, Miss	64.9	....	78.2	....	51.5	....	90	1884	....	....	30	1886, '87	....	....
Wilmington, N.C	62.1	55.6	69.1	64.7	55.1	46.5	93	1884	83	1877	32	1876	20	1872

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, with the climatic conditions controlling the yield of cotton in each State of the cotton belt.*

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1878.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	3.81	—0.97	71.1	—4.3	36	43	57	3.27	—2.74	79.3	+0.5	24	32	68	8.24	+1.83	78.4	+1.2	56	49	51
South Carolina	4.44	—0.33	......	......	37	50	50	8.98	+3.18	......	......	55	42	58	8.10	+2.14	......	......	42	45	55
Georgia	5.20	—0.04	78.2	0.0	45	57	43	6.11	+1.62	83.7	+2.7	40	45	55	6.05	+0.55	83.8	+5.3	42	52	48
Florida	......	......	......	......	38	......	......	......	......	......	......	53	......	......	......	......	......	......	45	......	......
Alabama	6.15	+1.35	79.2	+1.4	37	53	47	3.31	—1.06	84.2	+0.3	37	52	48	7.82	+3.82	82.4	+3.5	44	45	55
Tennessee	4.62	—0.23	73.3	—2.7	43	50	50	5.73	+1.51	82.4	+3.2	40	39	61	4.53	+0.98	80.0	+2.8	34	39	61
Mississippi	7.21	+2.06	78.9	+0.1	50	50	50	3.99	—0.63	83.7	+2.4	23	36	64	4.47	+0.56	82.6	+2.4	42	39	61
Louisiana	7.50	+2.59	80.3	—0.5	45	49	53	6.16	+0.90	83.8	+0.5	48	39	64	3.80	—0.03	80.2	—1.9	48	36	64
Texas	2.43	—0.75	83.3	+2.0	33	......	......	6.79	+3.99	83.9	+0.7	30	......	......	6.34	+3.09	84.1	+1.9	40	......	......

States.	September.							October.							Injury to crop from insects, etc.	Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.			
1878.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°						
North Carolina	4.06	—1.18	74.4	—1.5	42	40	60	7.91	+3.61	63.5	—0.2	26	39	61	Small	0.38	221,699
South Carolina	8.56	+3.69	......	......	33	57	43	2.69	—0.76	......	......	23	42	58	...do	0.36	342,173
Georgia	8.02	+4.27	75.5	+3.0	38	57	43	1.97	—0.79	66.1	+1.5	25	39	61	Bad in sections.	0.36	530,763
Florida	......	......	......	......	63	......	......	......	......	......	......	26	......	......	......	0.24	39,256
Alabama	2.64	—0.10	76.3	—3.6	20	43	57	3.16	+0.69	65.6	+0.8	21	45	55	Bad in sections.	0.29	539,015
Tennessee	1.53	—1.62	70.1	—0.9	19	30	70	3.49	+0.60	61.8	+1.6	29	33	67	Small	0.59	430,190
Mississippi	2.46	—1.65	75.8	+0.4	......	37	63	3.90	+0.83	66.0	—0.3	29	36	64	Bad in sections.	0.30	748,952
Louisiana	2.15	—2.28	76.5	—0.6	32	33	67	3.37	—0.03	68.1	—0.3	29	33	67	...do	0.35	498,851
Arkansas	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	0.61	707,282
Texas	4.76	—0.96	78.9	—1.8	22	......	......	1.71	—2.14	73.9	+2.0	21	......	......	Small	0.61	1,105,133
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5,169,314

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, &c.*—Continued.

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1879.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	2.37	−2.41	73.4	−2.0	28	33	67	5.54	−0.47	78.1	−0.7	34	45	55	8.02	+1.61	75.7	−1.5	51	49	51
South Carolina	2.58	−2.19	......	......	23	40	60	7.63	+1.83	......	......	26	42	58	5.71	−0.25	......	......	39	55	45
Georgia	3.42	−1.82	77.8	−0.2	21	43	57	5.51	+0.52	82.1	+0.9	31	42	58	4.87	−0.63	77.4	−1.1	36	61	39
Florida	......	......	......	......	37	......	......	......	......	......	......	40	......	......	......	......	......	......	48	......	......
Alabama	2.97	−1.83	75.9	−1.9	43	40	60	5.10	+0.70	81.1	−2.8	55	52	48	4.93	+0.92	75.6	−3.3	47	48	52
Tennessee	2.55	−2.30	75.8	−0.2	28	43	57	4.92	+0.70	82.0	+2.8	37	45	55	4.03	+0.42	74.4	−2.8	31	45	55
Mississippi	2.96	−2.19	78.9	+0.1	27	37	63	4.36	−0.26	83.2	+1.9	29	45	55	6.50	+2.59	77.9	−2.3	39	45	55
Louisiana	2.53	−2.38	80.7	−0.1	22	33	67	4.73	−0.53	83.8	+0.5	34	45	55	7.60	+3.77	80.0	−2.1	18	42	58
Arkansas	......	......	......	......	......	......	......	......	......	......	......	23	......	......	......	......	......	......	32	......	......
Texas	2.28	−0.90	79.4	−1.3	23	......	......	1.60	−1.20	84.9	+1.7	19	......	......	6.91	+3.66	81.9	−0.3	23	......	......

States.	September.							October.							Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.		
1879.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°					
North Carolina	5.68	+0.44	70.0	−5.9	28	40	60	2.79	−1.51	66.8	+3.1	23	45	55	0.35	216,978
South Carolina	3.63	−1.24	......	......	30	37	63	3.48	+0.03	......	......	35	52	48	0.32	300,173
Georgia	3.81	+0.06	72.2	−0.3	16	40	60	4.02	+1.26	67.9	+3.3	35	61	39	0.35	551,893
Florida	......	......	......	......	66	......	......	......	......	......	......	58	......	......	0.23	37,707
Alabama	1.44	−1.30	70.9	−9.0	23	30	70	6.65	+4.18	66.4	+1.6	47	58	42	0.38	715,020
Tennessee	2.01	−1.14	68.4	−2.6	18	22	78	2.48	−0.41	65.1	+1.7	27	39	61	0.59	454,349
Mississippi	2.89	−1.22	74.0	−1.4	17	30	70	1.35	−1.78	68.7	+2.4	16	35	64	0.41	849,400
Louisiana	2.05	−2.38	76.6	−0.5	15	30	70	0.94	−2.46	70.4	+2.0	24	42	58	0.45	593,431
Arkansas	......	......	......	......	3	......	......	......	......	......	......	16	......	......	0.61	719,583
Texas	6.34	+0.62	78.7	+1.6	18	......	......	2.19	−1.66	72.2	+0.3	19	......	......	0.39	752,500
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5,191,034

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, &c.*—Continued.

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1884.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	6.12	+1.34	71.8	−2.6	40	50	50	9.37	+3.36	78.0	−0.8	47	45	55	6.03	−0.38	76.1	−1.1	35.	52	48
South Carolina	6.72	+1.95	74.2	−3.8	50	67	33	6.34	+0.54	80.8	−1.4	36	45	55	8.09	+2.13	78.1	+0.3	48	45	55
Georgia	8.15	+2.91	78.0	−0.2	50	60	40	3.12	−1.37	80.4	−0.6	32	39	61	4.74	−0.76	77.6	−0.9	38	39	61
Florida	7.14	+1.38	77.2	−3.0	50	......	......	6.94	+1.70	82.0	−0.1	55	......	......	5.13	−1.12	80.4	−1.1	54	......	......
Alabama	8.82	+4.02	74.6	−3.2	57	57	43	4.18	−0.22	79.4	−4.5	44	42	58	2.25	−1.76	77.2	−1.7	23	36	64
Tennessee	6.37	+1.52	73.0	−3.0	57	60	40	4.72	+0.50	77.8	−1.4	48	49	51	2.94	−0.67	75.2	−2.0	23	39	61
Mississippi	4.92	−0.23	77.4	−1.4	47	45	55	4.78	+0.16	83.4	+2.1	27	36	64	1.31	−2.60	79.8	−0.4	16	29	71
Louisiana	6.41	+1.50	79.4	−1.4	47	43	57	2.09	−3.15	85.8	+2.5	23	36	64	1.43	−2.40	81.5	−0.6	19	33	67
Arkansas	2.30	−2.03	75.6	0.0	20	......	......	5.11	+1.12	81.5	+0.8	29	......	......	3.50	−0.29	76.8	−2.0	24	......	......
Texas	4.77	+1.59	77.6	−3.1	22	......	......	0.69	−2.11	82.8	−0.4	6	......	......	2.23	−1.02	81.0	−1.2	13	......	......

States.	September.							October.							Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.		
1884.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°					
North Carolina	3.52	−1.72	74.5	−1.4	13	30	70	1.15	−3.15	67.3	+3.6	13	29	71	0.38	398,200
South Carolina	4.40	−0.47	74.7	+2.1	16	33	67	0.12	−3.33	68.9	+3.4	13	23	77	0.29	469,600
Georgia	2.96	−0.79	75.9	+3.4	20	23	77	1.27	−1.49	69.7	+5.1	12	20	80	0.26	752,500
Florida	4.71	−2.65	79.2	+0.7	32	......	......	2.23	−3.60	73.6	+3.3	17	......	......	0.23	58,900
Alabama	1.45	−1.29	75.2	−4.7	12	23	77	3.02	+0.55	69.5	+4.7	15	22	78	0.24	630,400
Tennessee	2.44	−0.71	74.2	+3.2	18	40	60	2.44	−0.45	65.6	+2.2	16	29	71	0.38	310,700
Mississippi	2.50	−1.61	78.8	+3.4	28	33	67	0.99	−2.14	70.0	+3.7	23	29	71	0.40	901,300
Louisiana	2.61	−1.82	80.5	+3.4	27	30	70	3.07	−0.33	71.2	+2.8	24	33	67	0.53	490,200
Arkansas	5.02	+1.66	77.0	+3.6	30	......	......	1.31	−1.51	64.9	+1.0	11	......	......	0.44	518,500
Texas	5.21	−0.21	79.1	+2.0	32	......	......	7.52	+3.67	68.6	−3.3	36	......	......	0.37	1,118,000
Total	....	....	......	....	......	......	......	....	....	......	....	......	......	......	......	5,648,300

TABLE XXV.—*Exhibiting two years of good crops and two years of poor crops, &c.*—Continued.

States.	June.							July.							August.						
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.
1886.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°			
North Carolina	8.58	+3.80	72.7	—2.7	53	60	40	9.86	+3.85	77.1	—1.7	42	45	55	6.95	+0.54	75.6	—1.6	50	58	42
South Carolina	10.16	+5.39	77.1	—0.9	57	67	33	6.02	+1.22	79.8	—2.4	42	48	52	1.42	—4.54	78.8	+1.0	36	55	45
Georgia	8.52	+3.28	78.4	+0.2	50	60	40	5.54	+1.05	78.1	—2.9	45	42	58	4.02	—1.48	77.9	—0.6	36	48	52
Florida	6.75	+0.99	80.5	+0.3	47	......	......	11.85	+6.67	80.5	—1.6	71	......	......	7.38	+1.13	80.7	—0.8	45	......	......
Alabama	5.56	+0.76	75.8	—2.0	60	60	40	3.68	—0.72	77.6	—6.3	39	39	61	3.38	—0.63	78.6	—0.3	36	45	55
Tennessee	6.79	+1.94	72.7	—3.3	48	63	37	4.56	+0.34	76.4	—2.8	29	33	67	5.72	+2.11	76.2	—1.0	40	51	49
Mississippi	9.50	+4.35	76.8	—2.0	60	53	47	2.37	—2.25	79.9	—1.4	33	33	67	3.22	—0.69	80.2	0.0	37	36	64
Louisiana	6.73	+1.82	78.7	—2.1	55	53	47	3.47	—1.79	80.7	—2.6	45	39	61	3.00	—0.83	81.7	—0.4	29	22	78
Arkansas	7.69	+3.36	74.2	—1.4	50	......	......	2.80	—1.19	79.4	—1.3	36	......	......	3.57	—0.22	79.1	+0.4	26	......	......
Texas	4.66	+1.48	77.8	—2.9	30	......	......	2.46	—0.34	80.8	—2.4	29	......	......	2.75	—0.50	81.1	—1.1	20	......	......

States.	September.							October.							Bales per acre.	Total number of bales.
	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent of clear days.	Precipitation.	Precipitation departure.	Mean temperature.	Temperature departure.	Per cent. of rainy days.	Per cent. of cloudy days.	Per cent. of clear days.		
1886.	*Inches.*	*Inches.*	°	°				*Inches.*	*Inches.*	°	°					
North Carolina	2.01	—3.23	73.6	—2.3	16	40	60	0.45	—3.85	63.4	—0.3	1	23	77	0.38	407,230
South Carolina	2.06	—2.81	75.3	+2.7	20	40	60	0.59	—2.86	62.5	—3.0	1	23	77	0.32	554,652
Georgia	0.94	—2.81	74.9	+2.4	20	37	63	0.36	—2.40	63.4	—0.2	13	21	79	0.32	960,025
Florida	2.53	—4.83	79.0	+0.5	37	......	......	1.73	—4.10	69.7	—0.6	19	......	......	0.27	73,837
Alabama	1.44	—1.30	75.5	—4.4	13	37	63	0.36	—2.11	64.3	—0.5	3	22	78	0.27	760,447
Tennessee	3.92	+0.77	71.6	+0.6	23	37	63	0.66	—2.23	59.6	—3.8	13	22	78	0.37	321,638
Mississippi	5.52	+1.41	76.0	+0.6	37	40	60	0.48	—2.65	65.7	—0.6	10	19	81	0.40	1,019,470
Louisiana	4.54	+0.11	77.4	+0.3	39	40	60	1.91	—1.49	67.1	—1.3	10	19	81	0.49	487,722
Arkansas	5.23	+1.87	73.8	+0.5	30	......	......	1.30	—1.52	61.6	—2.3	13	......	......	0.45	610,666
Texas	13.78	+8.06	77.9	+0.8	50	......	......	2.02	—1.83	67.3	—4.6	13	......	......	0.38	1,332,027
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	6,527,714

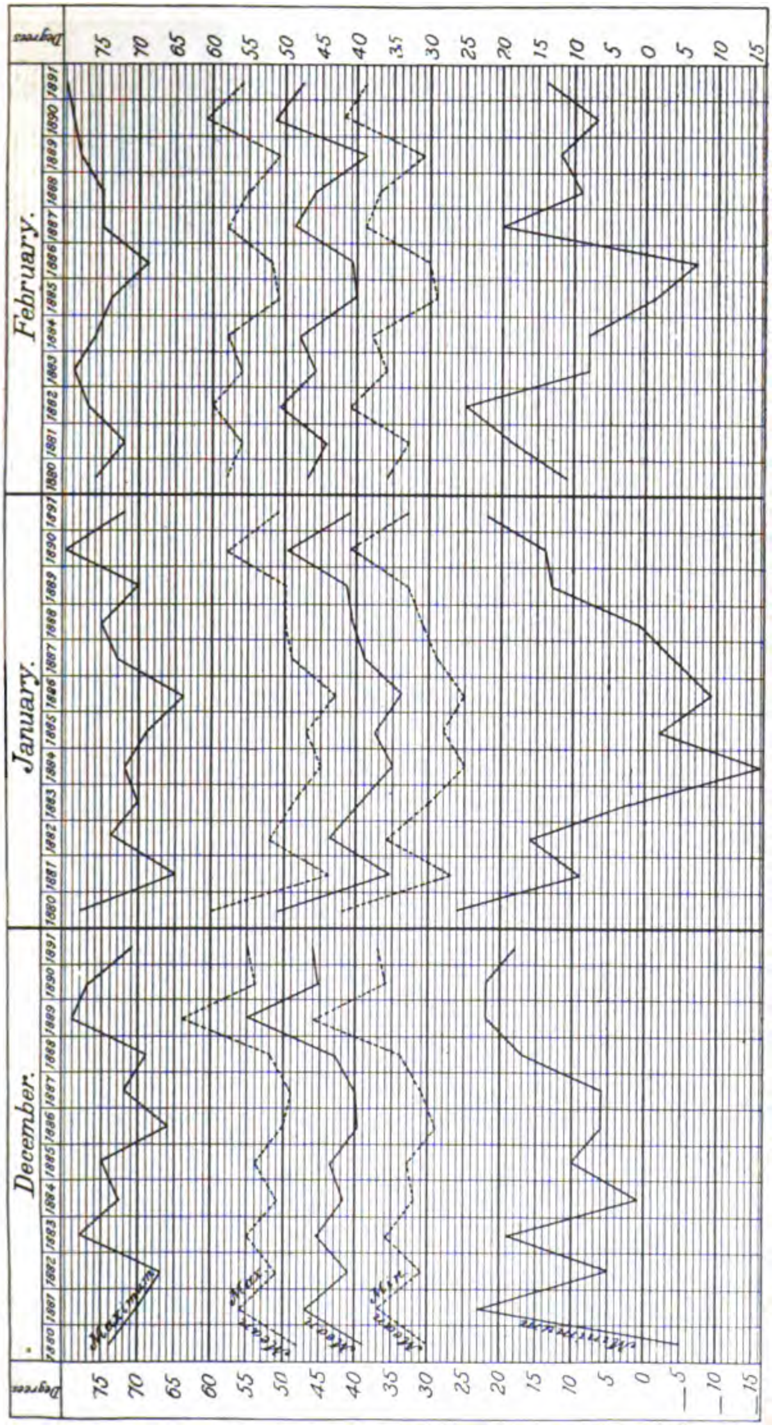


CHART I.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the winter months along the northern limits of the cotton belt.*

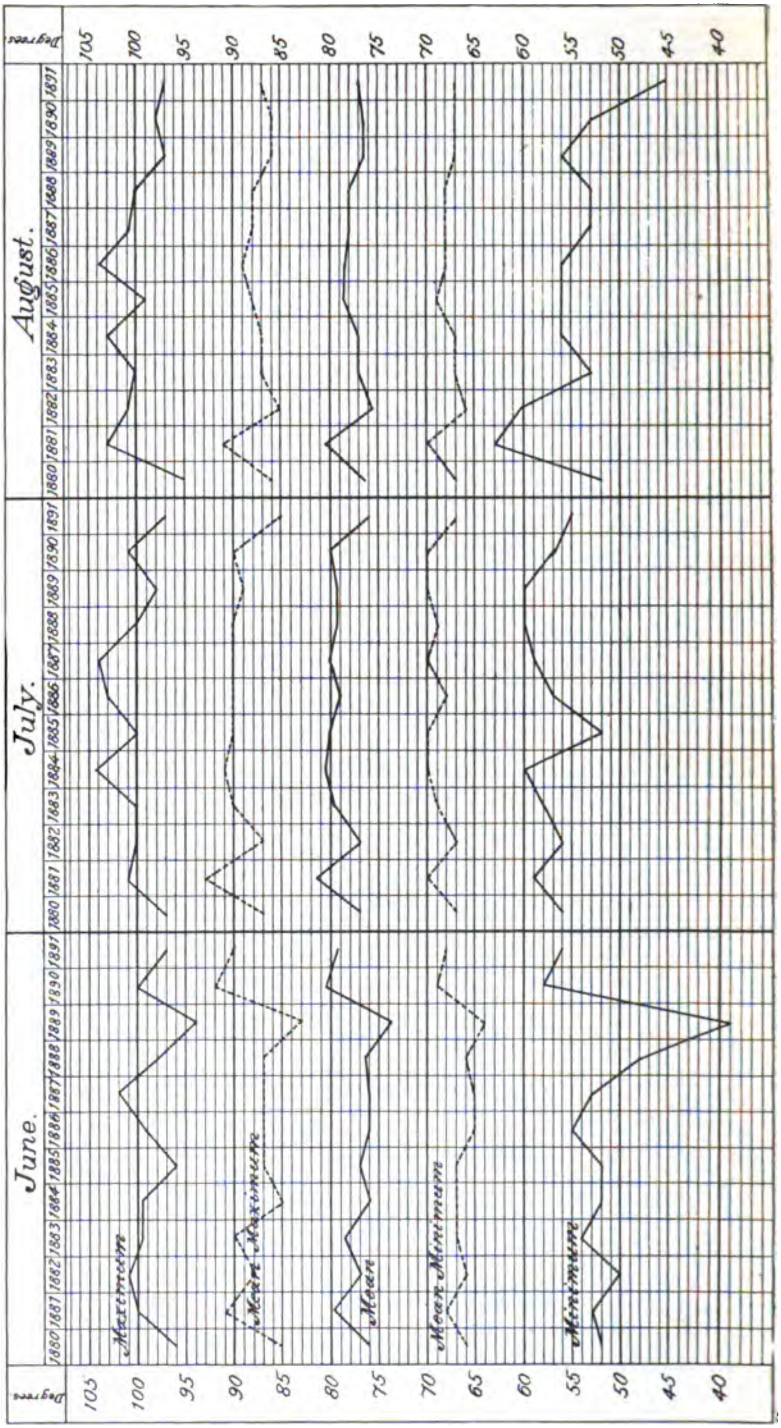


CHART II.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the summer months along the northern portions of the cotton belt.*

Chart III.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the winter months along the middle portions of the cotton belt.*

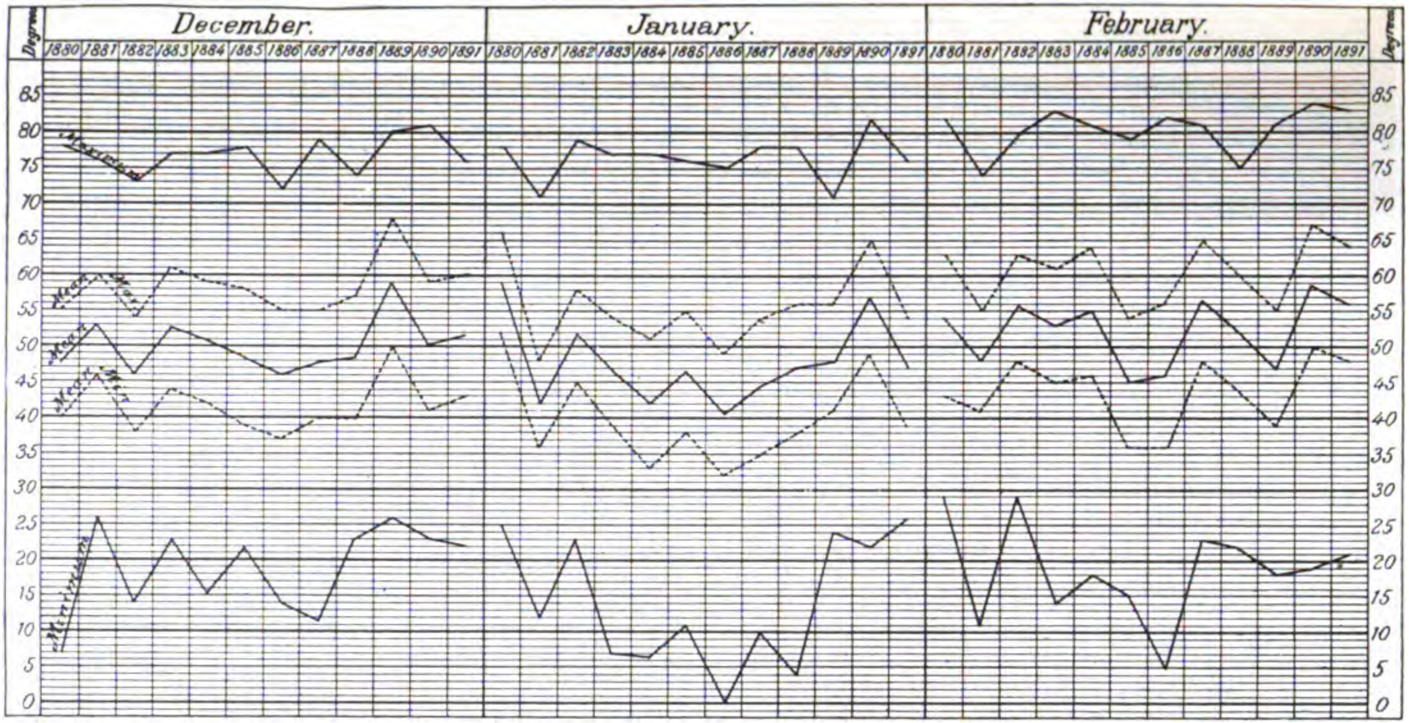
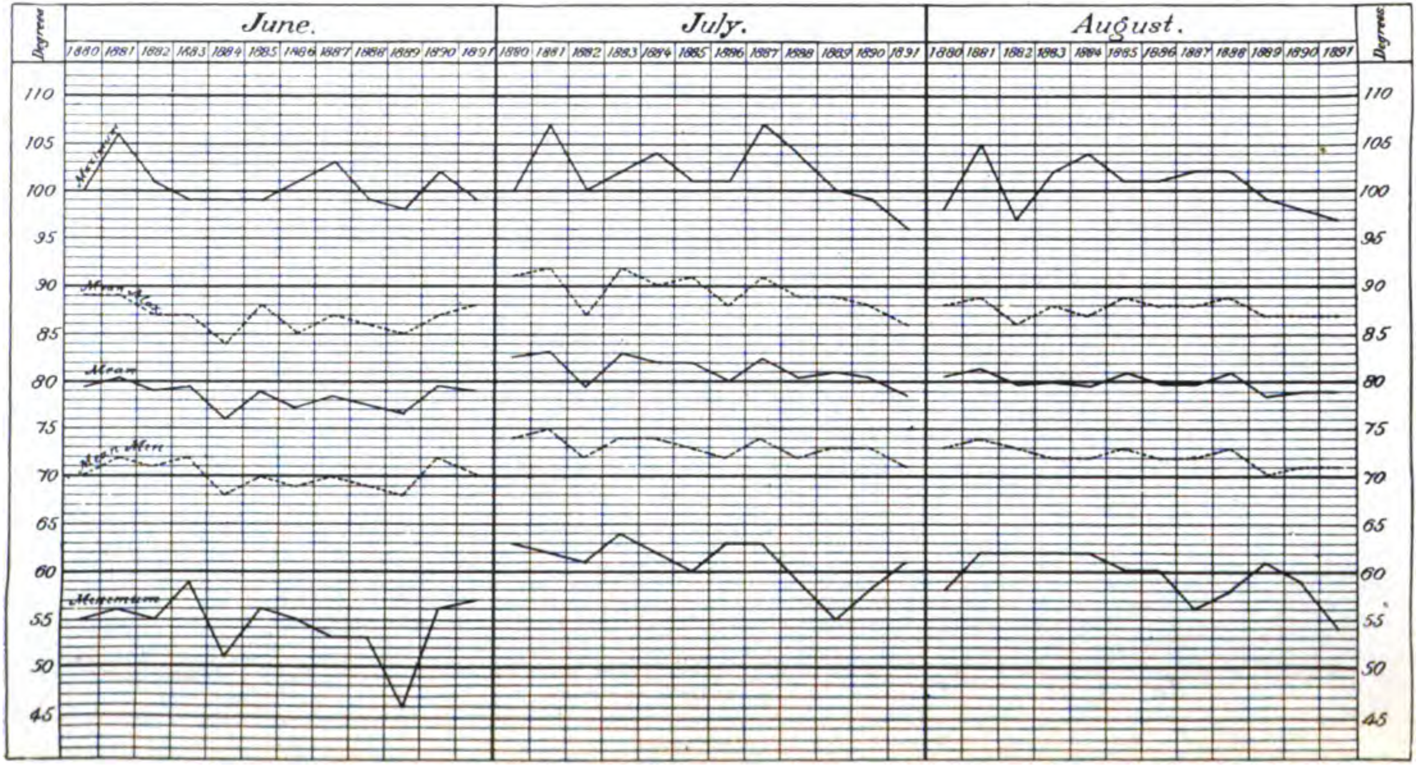


CHART IV.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the summer months along the middle portions of the cotton belt.*



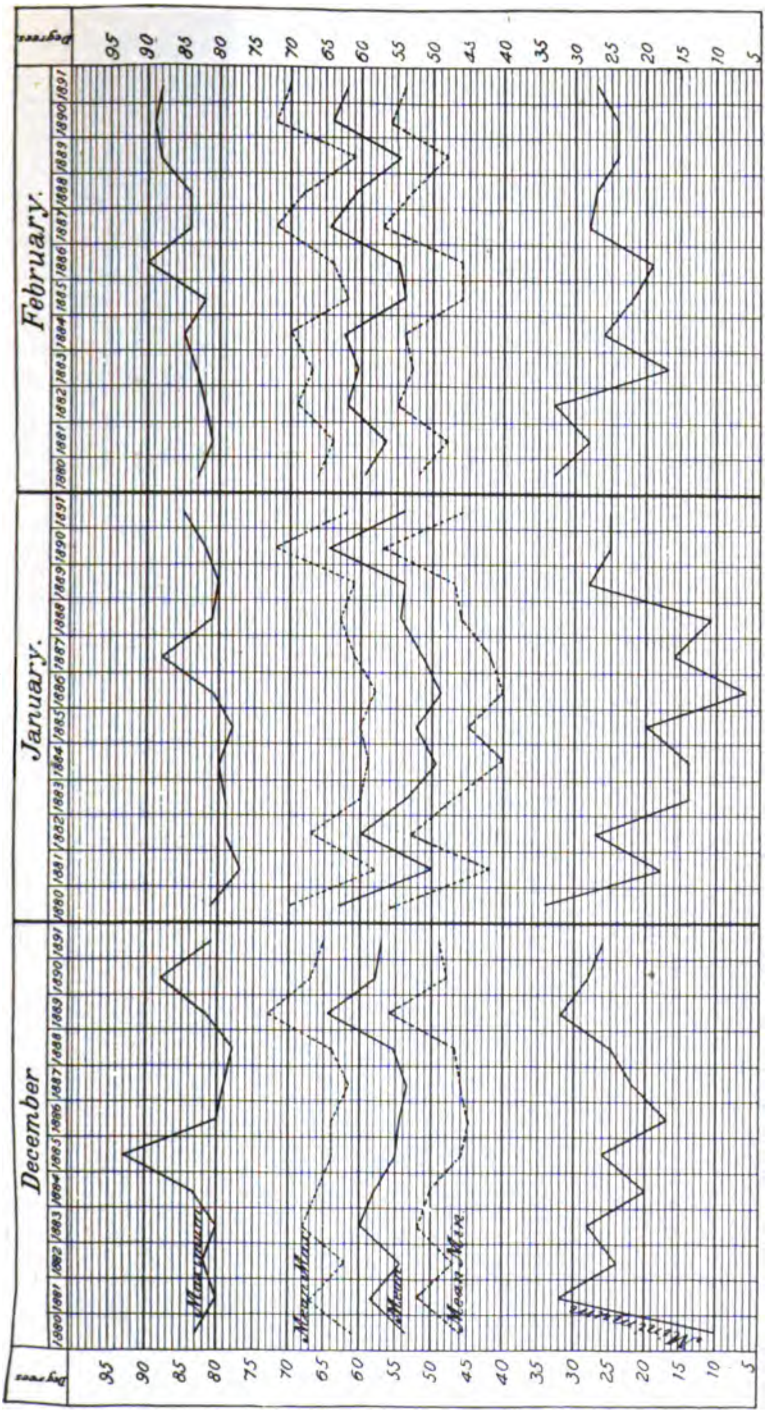
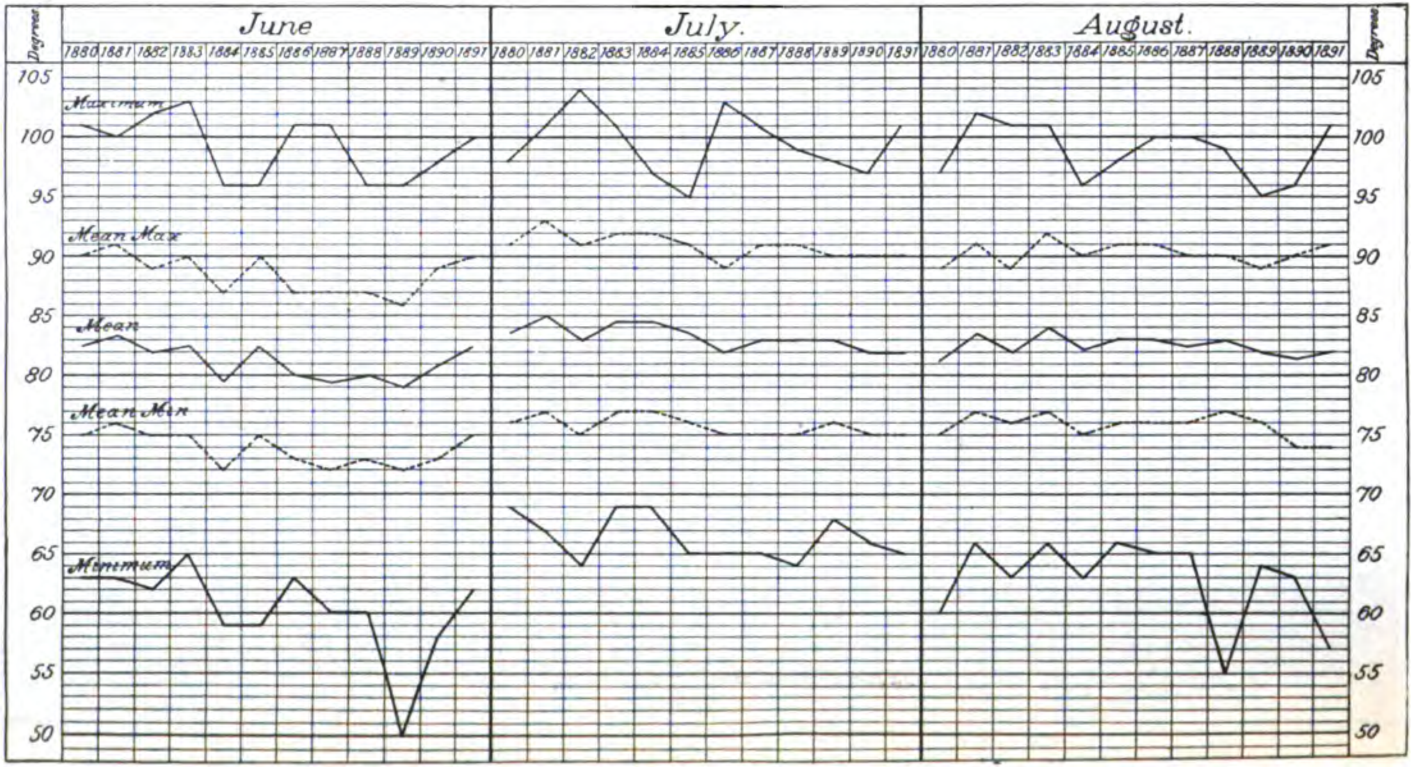
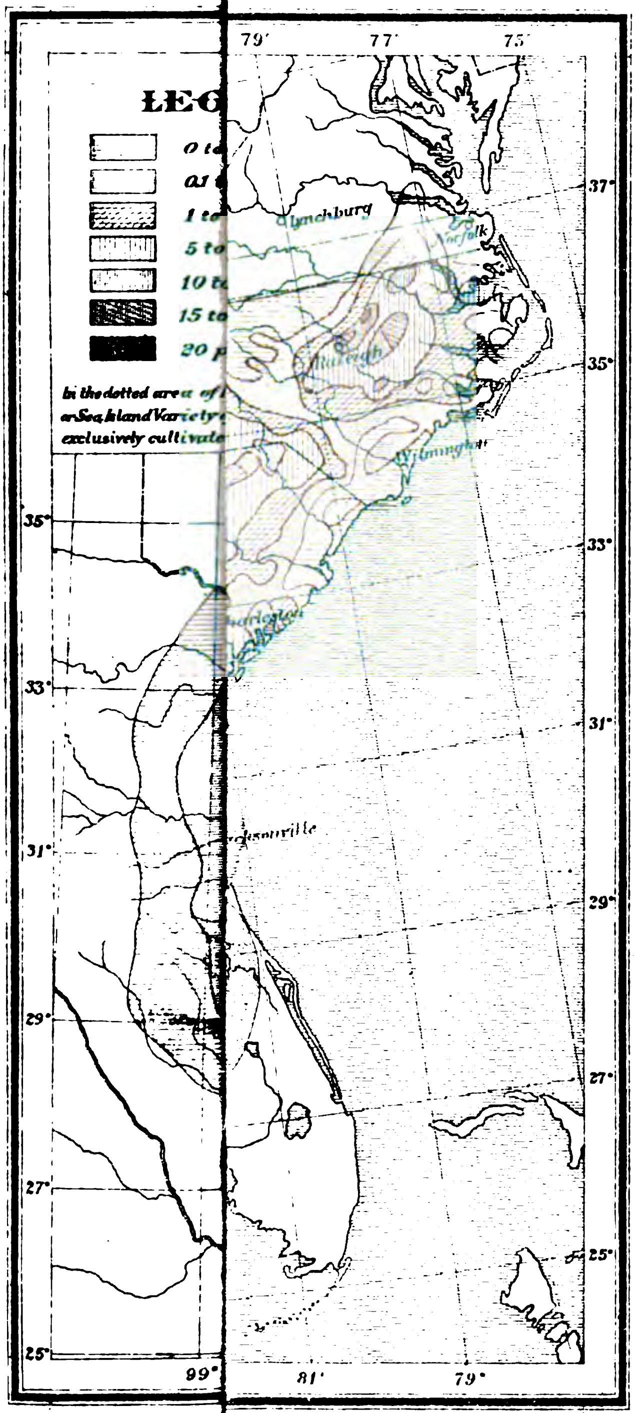


CHART V.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the winter months over the southern regions of the cotton belt.*

CHART VI.—*Mean temperature, mean maximum, mean minimum, maximum and minimum for the summer months along the southern regions of the cotton belt.*

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or Sea Island Variety
exclusively cultivate
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Norfolk
Raleigh
Wilmington
Charleston
Jacksonville
79°
77°
75°
37°
35°
33°
31°
29°
27°
25°
99°
81°
79°

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 9.

REPORT

ON THE

FORECASTING OF THUNDERSTORMS

DURING THE

SUMMER OF 1892.

BY

N. B. CONGER,
INSPECTOR, WEATHER BUREAU.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
1893.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., March 16, 1893.

Sir: I have the honor to transmit herewith a report on the "Forecasting of Thunderstorms during the Summer of 1892," by Mr. N. B. Conger, Inspector, Weather Bureau.

This work was carried out under the auspices of the State Weather Service Division of this Bureau, with the view of ascertaining whether or not it is feasible for the local forecast officials at the various State centers to forecast for their respective districts the occurrence of these severe secondary storms. This report shows the degree of success attained. I recommend that it be published as a Bulletin of this Bureau.

Very respectfully,

Mark W. Harrington,
Chief of Weather Bureau.

Hon. J. Sterling Morton,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., February 28, 1893.

SIR: I have the honor to submit herewith my report on the investigation and forecasting of thunderstorms during the summer of 1892, a work to which I was assigned in May last, with station at Detroit, Mich.

There are also appended papers of similar purport by Messrs. Robert DeC. Ward, Cambridge, Mass., and Charles M. Strong, Columbus, Ohio, for their respective districts, New England and Ohio.

Very respectfully,

N. B. CONGER,
Inspector, Weather Bureau.

The CHIEF OF THE WEATHER BUREAU,
Washington, D. C.

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II. Air pressure and temperature at 8 a. m., June 16, 1892, with thunderstorms of same date.
III. Air pressure and temperature at 8 a. m., June 17, 1892, with thunderstorms of same date.
IV. Air pressure and temperature at 8 a. m., July 15, 1892, with thunderstorms of same date.
V. Air pressure and temperature at 8 a. m., July 16, 1892, with thunderstorms of same date.
VI. Air pressure and temperature at 8 a. m., July 26, 1892, with thunderstorms of same date.

INVESTIGATION OF THUNDERSTORMS DURING THE SUMMER OF 1892.

INTRODUCTORY REMARKS.

The Chief of the Weather Bureau, desiring to have a practical study of thunderstorms made during the summer of 1892 to ascertain the feasibility of making thunderstorm forecasts and to obtain a better knowledge of their characteristics, began preparations for systematic work in this direction during the winter, and on April 1 the following circular was issued and sent to selected stations (named in the last paragraph of the circular), from whence they were issued to voluntary observers and others interested in this class of work, with a supply of record cards, for the purpose of rendering reports of storms occurring in their respective localities. In a few of the States the reports were numerous and well distributed, while in others there were very few reporters secured, and some of these reported for a short time only.

The following is a copy of the circular above referred to:

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., April 1, 1892.

THUNDERSTORM OBSERVATIONS.

The Weather Bureau desires to give special attention to the observation and investigation of thunderstorms and attending phenomena during the summer of 1892, and with this end in view the co-operation of meteorological observers and others interested is earnestly solicited. The object of this work is to gather material to be utilized in the study of these storms and the attending atmospheric conditions with a view to predicting the occurrence of this class of storms for special localities in time to make the forecast of value to agricultural interests. The great advantage of receiving information as to the actual prevalence of violent thunderstorms in certain quarters of your State, with reliable predictions as to when such a storm will likely reach your own community, should be apparent to all, and as there is no class of citizens which would not be benefited by a system that would make such work possible, there should be no difficulty in securing the voluntary assistance of observers in such numbers as to supply ample material for this work. Upon such voluntary co-operation on the part of observers the success of the plan will largely depend.

The field chosen for the proposed system of observations for the approaching season will embrace the region from the upper Mississippi eastward to the Atlantic coast, including the New England States, and if the results anticipated are realized, next year the territory will probably be extended to embrace the entire country.

For the purpose of recording observations postal cards have been prepared. These will be forwarded first to certain designated sub-centers, and later to the central office of the Weather Bureau at Washington.

For the guidance of those who desire to kindly assist in this work the following instructions are given:

Time.—Standard time, by which railroad trains are run, should be used in all cases. See that your watch is correct to within at least one minute.

Thunder.—Record should be made whenever a thunderstorm can be seen or heard. Thunder without rainfall should be noted, and in such cases care should be taken to state that no rain fell.

Movement.—The direction of movement of the storm should be carefully recorded; also any peculiar features of the movement, such as a dividing of the clouds.

Wind.—Direction should be given as shown by a vane on a high spire or building when possible. Take care that the north mark is correct. Record directions as N., NE., E., SE., etc., or if special care is taken, as N., NNE., NE., ENE., etc. The force of the wind may be described as calm, light, moderate, brisk, high, very high. A "very high" wind breaks limbs from trees and may do injury to some buildings. The time and direction of strong gusts or squalls are important.

Temperature.—The thermometer that is used should be as good a one as can be had. It should be hung out of doors in the shade, four or five feet above the ground, and over grass when possible. It should be freely open to the wind, but protected from the sun and rain; if near a house it should be on the north side, and not exposed to glaring reflections from white buildings or sandy roads. It is not necessary to estimate the fractions of a degree. The change of temperature accompanying a change of wind should be carefully noted.

Rain.—The time of beginning and ending of rain should be noted as closely as possible. The amount may be estimated as very light, light, moderate, heavy, very heavy, or the depth of rain may be measured as collected in a rain gauge. If the observer has no rain gauge a pail or can with vertical sides may be used, when the amount can be measured with a common rule. The amount of rain collected will often be less than one-tenth of an inch, and will seldom be more than one inch, unless the rain be long continued: its depth should be measured as soon as convenient after the rain ceases. When rain is seen falling in the distance it should be noted under "Remarks," as light rain to northwest at 4.25 p. m. The character of the rain, whether falling steadily or in brief showers, etc.. descriptive notes of clouds, and any other fact worthy of special mention may also be noted under this heading.

Miscellaneous.—Photographic views of lightning flashes and thunderstorm clouds will be of special interest and importance, and are desired whenever it may be convenient to furnish them.

If you cannot take the observations above described will you be kind enough to give this circular to some one in your neighborhood who may be willing to do so?

When the space under "Remarks" proves insufficient for the report additional cards may be used, care being taken to date and number them in consecutive order.

Observations above referred to are desired only from May 1 to August 31.

Persons who may desire to act as thunderstorm observers in the several States will be furnished with postal cards and instructions, upon application to the observers of the Weather Bureau in charge of the central stations of their respective States, as follows: New England, Observer, Weather Bureau, Cambridge, Mass.; New York, Observer, Weather Bureau, Ithaca, N. Y.; Pennsylvania, Observer, Weather Bureau, Philadelphia, Pa.; New Jersey, Observer, Weather Bureau, New Brunswick, N. J.; Ohio, Observer, Weather Bureau, Columbus, Ohio; Michigan, Observer, Weather Bureau, Detroit, Mich.; Indiana, Observer, Weather Bureau, Indianapolis, Ind.; Wisconsin, Observer, Weather Bureau, Milwaukee, Wis.; Illinois, Observer, Weather Bureau, Springfield, Ill.; Missouri, Observer, Weather Bureau, Columbia, Mo.

MARK W. HARRINGTON,
Chief of Weather Bureau.

The following is a copy of the card record used by the thunderstorm reporters, on the reverse side of which is the address of the proper Weather Bureau official to whom it was sent:

Form No. 1077—Met'l. Thunderstorm report.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

P. O., ... County, ... State, ...

Date of storm, ..., 189.. ; Kind of time used, ...

									Highest wind.		Storm moved
Thunder.	First heard.	m.	Rain or snow.	Began...	m.	Hail.	Began ..	m.	Time	m.	from
	Loudest ...	m.		Ended ..	m.		Ended..	m.	Direction.		.... to
	Last heard .	m.		Amount.			Size		Force * ...		....

Wind.	Before.	During.	After.
Direction.			
Force * ...			
Temperature ..			

NOTE.—Under "Remarks" add such miscellaneous data as to loss of life or damage due to lightning; growth and movement of clouds; whether storm was moderate, severe, or violent.

* Wind should be expressed as calm, light, fresh, brisk, high, very high, tornado.

Remarks.

Only two cards left make (   ) cross.

............................, *Observer.*

GENERAL DISCUSSION.

The investigation of thunderstorms during the months of June, July, and August was conducted in the following States: Missouri, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, New Jersey, and the New England States, and the comments made in this discussion are confined to this territory. Forecasts of thunderstorms were made by Weather Bureau officials at St. Louis, Mo., Chicago, Ill., Milwaukee, Wis., Indianapolis, Ind., Columbus, Ohio, Detroit, Mich., Pittsburg, Pa., Albany, Buffalo, and New York, N. Y., Philadelphia, Pa., and New Brunswick, N. J. These stations had at least three sub-stations to the west of them which reported by telegraph the occurrence of thunderstorms between the hours of 8 a. m. and 6 p. m., except in a few cases where telegrams were sent at any time during the twenty-four hours, it being the intention to test the feasibility of making forecasts of thunderstorms on information received from the west.

The charts accompanying this report show the weather conditions over the United States east of the Rocky Mountain slope at 8 a. m. (Eastern standard time), and the thunderstorms which occurred during the day in the different sections of the above-mentioned territory.

These thunderstorms are represented on the charts in their movements and location by small arrows, flying in the direction in which the storm moved; the arrows with one feather represent the storms occurring between midnight and noon; arrows with two feathers represent the storms occurring between noon and midnight. It will be noticed that a large majority of these storms occurred during the afternoon or evening.

In this investigation it is only intended to bring out the salient points of the practical results of the season's work, and not to touch upon any theoretical point in the development of thunderstorms, and with this statement plainly outlined it will only be necessary to follow the attending thunderstorm conditions to prove: (1) that thunderstorms travel in well-defined areas from the Mississippi, (2) that sporadic thunderstorms exist which occur during heated terms and cover but limited territory, (3) that there is a relation to areas which pass to the eastward, (4) that there occur thunderstorms in districts which have been covered by previous storms on the same date, (5) that thunderstorms die out during the night and revive again the next day farther east, (6) and the feasibility of thunderstorm forecasting. In considering these different subjects several of the best authenticated types have been charted to convey a better understanding of their peculiarities.

The data have been compiled from a large number of card reports from correspondents in the territory named and have been condensed from separate State charts to one general chart for the entire district, together with the pressure and temperature lines at 8 a. m. of the same date.

The first subject to be considered is the movement of the thunderstorm areas from the west to east; there are several well-defined types of thunderstorm progressing steadily eastward, which will be noticed in order: On June 6, a thunderstorm belt was noticed in Wisconsin from 12.45 to 8 p. m., and while not reported in regular cadence in Illinois, was reported in Indiana at 1 a. m. of the 7th, and on the same date in Michigan from 2 to 5 a. m., and in Ohio from 2 a. m. to 2 p. m. In this area the regular progression was well defined. This area appeared to die out in Ohio. (See Chart I.)

On June 8 thunderstorm conditions were present in southern Michigan, northern Indiana, and Ohio; the general movment of the thunderstorms was to the northeast, while the belt appeared to spread to the southeast. The development of the belt began about 7 a. m. in northern Indiana and southern Michigan and moved in regular cadence through Ohio, reaching the southeast border at about 6 p. m.; the northeast portion of the storm moved into New York at 4.50 p. m. and died out by 7.45 p. m., before reaching central New York. Sporadic storms occurred later in the afternoon in Indiana. A secondary belt developed in Wisconsin from 6.45 a. m. to 11.15 a. m.; this belt was reported in southern Michigan at noon and progressed regularly across the State, reaching the eastern border at 5 p. m., where the record for the night lapses, but it appeared again at 11 a. m. of the

9th in western New York and moved steadily east, reaching the eastern border of the State at 4 p. m., and was reported in New England from 4.56 to 9 p. m., but its force decreased with its eastward movement. This thunderstorm belt will be again referred to in connection with thunderstorms occurring in a territory where a previous thunderstorm has occurred the same day, also in connection with thunderstorms dying during the night and reviving again the next day farther east.

The next well-defined type of thunderstorms, moving in regular progression from the west to the east, occurred on June 16, when thunderstorm conditions developed about 2 p. m. in Wisconsin and, traveling east, left the State about 5 p. m.; it was reported on the west shore of Michigan at 7 p. m., and extending south into northern Indiana, passed eastward, leaving Michigan at 11 p. m. The southwest portion of the storm area was reported in northeastern Ohio at 5.30 a. m. of the 17th and the area proper was noticed in western New York and Pennsylvania at 2.30 a. m. of the 17th, advancing steadily eastward, passed into Vermont at 10.30 a. m., and into Massachusetts and Connecticut a little after noon, and passed out of southeastern Massachusetts about 9 p. m. This is a well-developed type of the thunderstorms moving in regular progression from the Mississippi River to the Atlantic coast, and is authentically traced throughout the entire path. The thunderstorm belts of July 15 and 16 are also well-defined types of these thunderstorms. (See Charts II–V.)

The charts accompanying this report indicate the position of the pressure and temperature lines on these dates, so that it will not be necessary to trace the low areas with the movement of the thunderstorm belts. The fact that the weather conditions as shown on the chart at 8 a. m. are advancing eastward during the day should not be lost sight of, and that the storms occur during the afternoon—the change of base must be taken into consideration.

HEAT THUNDERSTORMS

This class of storms, which occur over a large territory without a definite path of progression and develop in the afternoon, is well illustrated in the series of storms which were reported from the Mississippi River to the Atlantic coast on July 26, during the height of the hot wave which prevailed at that period. In Wisconsin, Ohio, southern New York, and northern New England these storms occurred in the forenoon, while in Illinois, Indiana, Michigan, Pennsylvania, New York, and southern New England the thunderstorms occurred during the afternoon, and there appeared to be no connection between the storms of the East and those of the West. (See Chart VI.) The thunderstorm conditions of July 27 are indicative of the same class of storms and appear to have no progressive movement.

It is found that two distinct thunderstorm belts may traverse the same territory and that the second storm does not appear to hold its force to the same extent after it reaches the territory which has been covered by a previous storm on the same date. This is well defined in the thunderstorm belt of June 6.

It is noticed that thunderstorm belts, moving eastward during the day, appear to lose their identity during the night and revive again farther east the next day. This action is especially noticeable in the thunderstorm belts of June 8, when the trail disappeared at 5 p. m. in Michigan and was found at 11 a. m. the next day in New York, but with reduced force or activity, and advanced east. Prof. H. A. Hazen, in his report on thunderstorms in 1886, notices the same action in these storms, and remarks on their peculiarity.

Thunderstorm conditions are usually found on the southeast quadrant of a low area, and generally in the belt of pressure of 30.0 inches. (See Chart IV.) This is the class of storms which generally have the progressive movement to the east, and have approximately the same velocity as the low area. Thunderstorms also occur on the southwest quadrant of the low area, but these are more liable to occur in the afternoon and be sporadic in character. When two low areas are in progress the crest of the high between them is found to be a favored locality for the development of thunderstorm conditions. Prof. von Bezold, of the University of Berlin, in his memoir on thunderstorms in 1883, observes this and makes special note of it. Thunderstorms are sometimes developed on the northwest quadrant of a low area, but this was only noticed when the temperature changes were sharp and sudden in that section. Storms of this class are rare, of short duration, violent in action, and cover but a narrow path. Thunderstorm belts are occasionally developed in high areas when the weather conditions are of an unsettled nature, and a long trough of nearly normal pressure extends over a large territory to the north of the center of the high.

While there are no infallible rules to be laid down for forcasting thunderstorms from the daily weather charts, yet there are certain conditions, indicating the development of a thunderstorm belt, which generally follows during the succeeding twenty-four hours. A noticeable feature of the a. m. weather charts for this season was the relation of the thunderstorm belt to the pressure line of 30.0 inches and the thermal line of 70°. It is found that during the season nearly 90 per cent of the thunderstorms occurred in the belt covered by the isobar of 30.0 and at or near the isotherm of 70°. The presence of a low area to the west, moving in behind a high area, should be watched with great care as the thunderstorm conditions are very liable to develop during the afternoon or evening; the sharp curvature of the isobar, especially where it touches or crosses similar sharp curves of temperature, has been found to be of value in forecasting. As before noted, thunderstorm conditions are generally found on the edges of low areas and are not reported in the centers, especially when the pressure decreases to 29.6 inches or below. When the thunderstorms occur on the southwest quadrant of a low area they are more liable to be sporadic in character, travel but a short distance, and soon die out; they represent a distinct type of thunderstorms and should not be classed with the thunderstorms which occur in the southeast quadrant of a low area.

In heated terms thunderstorms may be looked for along the line of change in pressure (30.0 inches) and where the temperature during the afternoon will continue high. These storm are more liable to occur the day after the maximum heat has passed. It is noticed during these periods that thunderstorm conditions are prevalent during the entire afternoon, and in many instances develop dry thunderstorms.

Where known thunderstorm belts exist to the west it is possible to forecast them for the territory farther east in the same manner as rain is now forecasted. The study of thunderstorms during this season has not established the fact that thunderstorms can be successfully forecasted for any specific locality, although with the aid of telephonic communication it has proved more feasible. The experiment of making forecasts on telegraphic warnings from stations to the west, some two hundred miles, has not proved of value as it appears that the belt may move rapidly in and cover the district with storms before the warnings can be issued to the public. With the warning coming from stations farther west, so that time may be had to issue the warnings to the public, it is considered that the method will meet with more success than during the season just passed.

In Michigan, where the telephone system was called into requisition, it was found to be of value in warning the public of approaching thunderstorms as the information was conveyed with great promptness over the telephone wires, and thus considerable time was saved. The State was divided into nine districts and each district had from three to six stations reporting to the section center, which reported direct to the central office at Detroit where the forecast was issued to the section where it was anticipated that the storm would occur during the day. If the storm was light the next station toward which the storm was moving was notified, and if it reached this section and appeared to be spreading the next contiguous section would then be notified. If the storm appeared to have considerable force the notice was sent into several sections at the same time. In many cases the warnings were issued from twelve to twenty-four hours in advance of the storm and must have been of considerable value to the general public as was evidenced by newspaper notices of the success of these forecasts. The telephone system was considered of no little value in this line, and this success was due in a great measure to the prompt action of the Michigan Bell Telephone Company in handling these reports, a work which was admirably accomplished.

The forecasting of thunderstorms from the daily weather maps for the season was fairly successful. Of the forecasts issued from Columbus, Ohio, the percentages of verification were: For June 90 per cent, July, 86, August, 50, the falling off in August being due to the small number of storms which occurred during that month. In Michigan, where the telephone system was used, the following percentages are given: June, 86 per cent, July, 85, August, 78. It must be considered in this that an effort was made to forecast all thunderstorms, whether light or heavy, and not to forecast the severe storms only. In Mr. Robert DeC. Ward's paper, which accompanies this report, will be found a comparison of the Washington and Boston forecasts for New England, which indicates that the preliminary work in this line has been fairly successful.

With the particular types noted in detail on the a. m. weather charts, it is considered that with the history of the movement of these thunderstorm belts chronologically from June 1 to August 31, 1892, a sufficient knowledge has been gained to encourage the further prosecution of this very interesting study during the coming season over a more extended territory. To make this of value to the agriculturist in bringing out the facts on which forecasting may be better prosecuted, there should be a larger number of reporters in the several States where this investigation is to be pushed so that it will be possible to have a report of every thunderstorm that occurs in a State, as it was found that in several of the States the absence of these reports made it exceedingly difficult to accurately trace the thunderstorm belt from one State to another. Believing that generous assistance will be readily given when it is understood that this subject is being investigated for practical results, and to increase the value of forecasts in this line, there should be at least one reporter in every two or three townships in the State, as the erratic progress of the thunderstorm could then be accurately traced over the entire district.

The experience of the past season leads to the belief that the forecasting of thunderstorms is practicable, and with the assistance of those interested in this class of information it is believed that important results will proceed from the investigation of these storms during the summer of 1893.

BRIEF DESCRIPTION OF THE MORE IMPORTANT ATMOSPHERIC CONDITIONS WHICH PREVAILED DURING THE PERIOD OF THUNDERSTORM INVESTIGATION.

JUNE, 1892.

1st.—A low area was central over Missouri, moving northeast, with a second low central north of Lake Huron. Thunderstorms occurred in Indiana, Ohio, Michigan, New York, and Pennsylvania. Those in Indiana and Pennsylvania were scattered and local in character. The general movement of these storms was to the northeast, the majority of them occurring in the afternoon.

2d.—A low area moved into the St. Lawrence Valley, with the territory covered by thunderstorms lying on the south side from New England west to Ohio, with a few scattered storms in Michigan. In this case the storms lay grouped along the isothermal line of 70°. A high area lay on the Atlantic coast, moving slowly northeastward.

3d.—A few scattered storms in Pennsylvania, Ohio, and Indiana in the afternoon. A long trough of low pressure extended from Pennsylvania southwest to the Gulf. A high area was central over Lake Superior, with a low area developing in Montana.

4th.—The low area remains nearly stationary, with a pressure of 30.10 inches over the Lake region and the Ohio Valley; the temperature ranging from 60° to 70°. Thunderstorms occurred in the central Ohio Valley during the afternoon, mostly confined to the Lake Erie watershed.

5th.—The low area moved slowly northeast, with a high area central over western Michigan, and one of 30.20 inches on the south Atlantic coast. The thunderstorm belt moved during the night east into New York and Pennsylvania. A local thunderstorm occurred in southern Michigan during the afternoon. The general movement of these storms was to the northeast, but some few moved to the southeast and one in Ohio is noted as moving towards the north. The a. m. weather chart indicates that the force of the thunderstorm belt is rapidly decreasing,

6th.—The development of the low area in the St. Lawrence Valley produced a belt of thunderstorms in the New England States, but the conditions were feeble and but few storms occurred. The low area advancing from the west reached the Dakotas, and a belt of thunderstorms was reported in Wisconsin and Illinois. The majority of these storms occurred in Wisconsin on the southeast quadrant of the low area central over the Dakotas.

7th.—The low area moved over Iowa with a very little change in temperature lines. The belt of thunderstorms moved east into Ohio and Michigan, where they occurred during the early morning, while in Illinois, Indiana, and western Michigan they occurred during the afternoon.

8th.—During the night, the low area which was central over the upper Mississippi Valley filled up, and a pressure of 29.9 inches extended from the Dakotas to the Gulf of Mexico, with a high area of 30.2 inches on the south Atlantic coast. Thunderstorms were frequent during the afternoon in Ohio and eastern Michigan, and local storms in western New York and Pennsylvania, and in Illinois, Indiana, and western Michigan. The chart indicates a hot afternoon, and the storms appear to be moving from all directions, a characteristic of heat thunderstorms.

9th.—With the formation of a low in the Lake region over Michigan and general unsettled weather conditions, it was found that the thunderstorm belt had advanced east and was found extending west from New England to Indiana. In the States of Ohio, Michigan, Indiana, and Illinois the storms were scattered and of local character.

10th.—Feeble thunderstorm conditions existed in New York and Wisconsin. A low area was moving off the coast, pressure 29.9 inches, and a low of some energy, pressure 29.5 inches, was central over Colorado. Temperature slightly below the normal.

11th.—No storms reported.

12th.—Conditions very feeble, and only two storms reported in New York and one in Wisconsin.

13th.—With a low area central near Marquette and a secondary low over Kansas, thunderstorms were reported in Wisconsin, Michigan, Indiana, and Illinois during the afternoon, with a few local storms occurring in the forenoon in Wisconsin. The general direction of these storms was from the southwest to the northeast, although a few moved from the northwest to the southeast in Wisconsin. There was a high area lying on the south Atlantic coast and a very uneven distribution of temperature in the Eastern States, and on the west of the low area the temperature gradients were very sharp. The movement of the low area was eastward into the St. Lawrence Valley.

14th.—The belt of thunderstorms moved east with the low area and was found in New York, Pennsylvania, New Jersey, and the New England States. The low area at 8 a. m. was central near Rockliffe, Ontario. In southern Ohio, along the river westward to the Mississippi, there occurred thunderstorms from early morning in Illinois to late in the afternoon in Ohio. These storms all occurred near the change line of 30.0 inches and in the isothermal belt of 70°.

15th.—The low area passed off and disappeared during the night of the 14th. A high area in the Mississippi Valley, moving east, was replaced by a low area moving in from Montana. Scattered storms were reported from New York, Ohio, Indiana, and Wisconsin; conditions very feeble and not sufficiently developed to make note of.

16th.—A slight depression was central just east of Sault Ste. Marie, extending southwest to Chicago, with a secondary low forming over Kansas. Temperature in the Mississippi Valley and lower Missouri Valley 80° and above. Thunderstorms occurred during the afternoon in southern Wisconsin, northern Illinois, and generally throughout Michigan. A few scattered storms occurred during the forenoon in Ohio, and general thunderstorms occurred in New York and Pennsylvania on the southeast quadrant of the low area central east of Sault Ste. Marie, while a high area covered the Atlantic coast, moving eastward.

17th.—The low area moved over the Missouri Valley and then took a northeasterly trend toward the Lake region. The high area is slowly moving off the coast. The isothermal line of 70° extended in an undulating curve from New England through New York, Ohio, Michigan, Indiana, Illinois, and thence southwest into Texas. Thunderstorms occurred in these States from the forenoon until late in the afternoon, but there seems to be no regular progression, and the separate storms moved but a short distance before they were exhausted. These storms were evidently caused by the heat wave that was passing at that time.

18th.—The low area remains stationary in the lower Missouri Valley, and east of this the pressure was about normal with a rain area extending from Kansas to New England. The pressure on the Atlantic coast being 30.2 inches. Thunderstorms were very frequent during the afternoon in Illinois, Indiana, southern Michigan, Ohio, western New York, and southern New England. A few scattered storms are noticed in Pennsylvania. The heaviest storms are reported in Ohio, southern Michigan, and northern Indiana and Illinois. The majority of these storms occurred in the afternoon, with a few scattered storms in the forenoon.

19th.—A few scattered storms occurred in New England and westward to Illinois. Two storms are reported on the upper Mississippi River at La Crosse and Red Wing; conditions feeble and the movement not well marked. Thunderstorms moved from the west to east. The low area passed northeast over the Lake region.

20th.—A low area of some magnitude developed during the night and was central at 8 a. m. over the St. Lawrence Valley, central pressure 29.5 inches; this area extended southwest into the lower Mississippi Valley and west to the Rocky Mountain slope, where a secondary low was forming. The thunderstorms were only reported in isolated places from New Jersey west to Illinois, and occurred in most cases about 2 p. m. There seemed to be no definite movement to these storms; they occurred at scattered points and died out before covering any extended territory.

21st.—The low area moved in from the northwest, and was central at 8 a. m. over Lake Superior. The isobar of 30.0 inches was south of Ohio and east of the Mississippi River. Thunderstorms were frequent in southern New England, western New York, Ohio, Michigan, and Indiana, with scattered storms during the forenoon in Illinois. The temperature was not high in the south, nor were the gradients to the west steep. The storms moved from all directions, and appeared to occur simultaneously in all sections during the afternoon, except in western Indiana where they occurred in the forenoon.

22d.—A low was central over Colorado with a northeast movement, and a second low over the St. Lawrence Valley. The isothermal line of 70° extends from Boston west to Colorado, with thunderstorms along this line from New England to the Mississippi River; the general movement of these storms was from west to east, except in Ohio, where the storms have no general direction. The storms which occurred during the afternoon of the 21st in Ohio and western New York have advanced east, and occur during the forenoon in eastern New York and New England, and some portions of Pennsylvania..

23d.—The low remains stationary in the St. Lawrence Valley with a second low area moving in from New Mexico. The thunderstorm belt has moved into New England, and thunderstorms occur during the morning from eastern New York to eastern Massachusetts, and during the afternoon over entire New England, and occur sporadically west to Illinois during the day.

24th.—The low was slowly moving out of the St. Lawrence Valley, and the air pressure is returning to the normal conditions throughout the district. The last of the thunderstorms of the 23d are reported to-day in the northern portion of New England, while in portions of Pennsylvania, Ohio, Indiana, and Illinois a few scattered storms are reported, but the conditions are too feeble to show any decided movement.

25th.—During the night of the 24–25th the low area extended south over the New England States, and light local storms are reported in Vermont, New Hampshire, and eastern Massachusetts, and a few isolated storms in eastern Pennsylvania. The thunderstorms in New England occurred during the afternoon and had no regular progression.

26th.—Sporadic heat storms occurred in northern New England, and in Michigan, Illinois, Indiana, and Wisconsin. Those in New England occurred on the southwest quadrant of the low area moving out, while those in the West occurred on the southeast quadrant of the low area moving in during the day from the extreme southwest. These storms occurred late in the afternoon and during the evening. Heat entered to some extent into the formation of these, and the movement was not especially marked.

27th.—The low area moved in during the early morning, and was central over Michigan at 8 a. m., with the east border over the New England States, and exhibited considerable energy, central pressure 29.5 inches. Thunderstorms occurred on the southeast quadrant of this low area from New England to Ohio, and had a general easterly movement, beginning early in the forenoon and extending late into the afternoon. In the Ohio Valley and New Jersey the storms occurred in the forenoon, while along the lakes they occurred from 1 p. m. to 3 p. m., and those in New England occurred somewhat later in the afternoon. The rainfall throughout this district was heavy, and the storms severe.

28th.—The low area moved over the St. Lawrence Valley, increasing in intensity, with a slight fall in temperature. These conditions would appear favorable for the formation of thunderstorms, but very few of them are reported, six in New England; and during the afternoon in Indiana, Illinois, Michigan, and Wisconsin a few scattered storms are reported. The movements of these storms were erratic and most of them occurred late in the afternoon or in the evening. A low area was forming in the Northwest, with an easterly movement during the evening.

29th.—The low area was central at 8 a. m. over Lake Superior, with a secondary low over Kansas, neither showing much energy. On the southeast quadrant of the low area central over Lake Superior, in New York and the New England States, thunderstorms occurred during the afternoon, and although not traced directly across, are evidently the same belt of thunderstorms that was noted in the Ohio Valley on the 28th, and developed again in the afternoon in New York and New England. The storms in New York had a general easterly movement, while those in Vermont moved from all directions. Late in the afternoon and in the evening thunderstorms occurred in southern Indiana and Illinois; storms feeble and the rainfall light. The temperature remains nearly stationary in all the districts.

30th.—This gives a fine type of thunderstorms progressing uniformly east with a low area. The low area moved east and was central at 8 a. m. over the St. Lawrence Valley, there having been a combination of the two lows during the night of the 29th, the area spreading to the southeast. Thunderstorms occurred during the early morning along the Ohio River, reached Pennsylvania about noon, spread over Pensylvania, New Jersey, and New England during the afternoon, and increasing in force with the increasing heat of the afternoon. It is remarkable how closely the storms in this case followed the isothermal line of 70° which did not cross the isobars but lay more parallel to these lines. The rainfall in these districts was quite heavy at a majority of the stations.

JULY, 1892.

1st.—The low area having passed off the coast and a high area central over the Ohio Valley, with a slight fall in temperature, the conditions were not favorable for the formation of thunderstorms, and only a few are reported, and these are local in character. Thunderstorms are reported in Pennsylvania at 9 p. m., and at Ithaca, N. Y., in the forenoon and again in the afternoon; there are also noted four thunderstorms in northwestern Missouri, which are probably due to thermal conditions.

2d.—At 8 a. m. a low area was central over South Dakota, spreading southeast, with the temperature on the increase. The rain belt at this hour had extended southeast into Indiana and east into Wisconsin. Thunderstorms began during the forenoon in Missouri and extended during the afternoon as far east as southern Michigan and along the Ohio River to Parkersburg, W. Va. It will be noted that a majority of these storms occurred from 3 p. m. to 6 p. m., and at Detroit, Mich., began at 11 p. m. and extended into the morning of the 3d. The rainfall was unevenly distributed, and at some stations was very heavy (this is especially noted in Illinois), and to the east the rainfall was lighter. It would appear that the thunderstorm belt was general over the States of Indiana, Illinois, Michigan, and western Ohio at about 3 p. m., just after the maximum heat of the day occurred, and the movement east of the storm-center was about equal to the eastward movement of the thunderstorm belt. The general trend of these thunderstorms was from the southwest to the northeast; the low area moved southeast and was central over Illinois in the evening, moving slightly to the northeast.

3d.—The low area passed northeastward and was central at 8 a. m. over western New York, and extended to the Atlantic coast. The belt of thunderstorms moved east with the low area and the storms were continuous from early morning in Indiana to late in the afternoon in New England. The storms in New England developed about 3 p. m. This is probably one of the best type of thunderstorm belts moving steadily eastward in progression from the west to the east, the storm belt spreading out as it extended eastward, the low area maintaining its intensity with slight changes of temperature. The thunderstorm belt in this case appears to hold its identity throughout the night and during the day.

9th.—No thunderstorms were reported from the 3d to the 9th, and on the latter date with a high area dominating the Atlantic slope and the temperature nearly normal, there was a small rain area in New York and New England which developed into thunderstorms about 3 p. m. in southeastern New York and New England only. The movement of these storms was reported from all directions.

No thunderstorms were reported from the 9th until the 12th.

12th.—At 8 a. m. a low area moving in from the west was central near Duluth, Minn., and thunderstorms began about 2 a. m. along the upper Mississippi Valley and extended across Wisconsin and northern Illinois into Michigan late in the afternoon. A few isolated storms were reported during the afternoon in New York and New England. The belt of thunderstorms was forming during the afternoon in Illinois, Indiana, Ohio, and New York as the low area was passing east, and the conditions were exceedingly favorable for a large extension of the belt during the night.

13th.—The low area moved east and was central at 8 a. m. over the St. Lawrence Valley, with a central pressure of 29.8 inches. The thunderstorm conditions began to develop about 2 a. m. in Missouri and extended rapidly eastward, reaching Pennsylvania, New York, and New England late in the afternoon and evening. The general trend of the thunderstorms was from the southwest to the northeast. In this case it would appear practical to have telegraphed the warnings of these thunderstorms from Wisconsin or Illinois to New York and New England and have accomplished some very effective work, as the movement of the belt of thunderstorms was sufficiently regular to have the warnings issued in time to be of value.

14th.—The western edge of the low area passed off the Atlantic coast and the thunderstorm belt passed off during the afternoon. In Missouri, Iowa, and western Wisconsin local thunderstorms were reported during the day. A low area was central over Montana, moving southeast. The thunderstorm conditions were feeble in all the districts.

15th.—The low area was central at 8 a. m. over Lake Superior, with a central pressure of 29.7 inches. The belt of thunderstorms began at 2.25 a. m. at Kansas City, Mo., and extended east during the day, reaching Indiana and Ohio from 12 noon to 3 p. m., and was reported in New York and New England from 9 p. m. until after midnight. The rainfall was not heavy and the force of the storm light. The storms did not cover any extended territory in any of the States, except New York. The thunderstorms in southeastern New York about midnight moved into New England and were dissipated after traveling a short distance.

16th.—The low area moved down the St. Lawrence Valley, and the belt of thunderstorms which was noted to the west on the 15th is noted in New England only during the afternoon, and was passing out to sea.

No storms were reported on the 17th.

18th.—Local thunderstorms were reported from 5 a. m. to 7 a. m. in northwestern Missouri and northwestern Wisconsin. Storms light and did not cover any extended territory.

19th.—With nearly normal conditions throughout the entire district, and a low forming in the extreme northwest, thunderstorms were reported at Red Wing, Minn., in the morning, and in the afternoon in Michigan and Missouri. The movement of these storms was reported from the northwest, except in Missouri, where the movement was erratic. The storms were local in character and showed no particular force.

20th—Thunderstorms began to develop at Des Moines, Iowa, at 8.45 a. m. and extended southeast, reaching the Mississippi River at 11.30 a. m., Springfield, Ill., at 2.30 p. m., and Indianapolis, Ind., at 3.53 p. m., and moved into the southwest portion of Ohio during the afternoon. A local storm occurred at Columbus, Ohio, at 2.25 p. m., one and one-half hours before the storm reached Indianapolis. The trend of this belt of thunderstorms was from the northwest, and the path is well marked and the rate of progression defined. The low area was central in Montana, and stationary. The pressure throughout the district traveled by the thunderstorms was 30.1 inches, and the temperature in the seventies at the 8 a. m. observation. The rainfall at the beginning of the thunderstorm was very heavy and decreased in amount as the storm progressed eastward.

21st.—Local thunderstorms were reported along the Mississippi River from Davenport, Iowa, to St. Louis, Mo., and local storms in Ohio and northern Michigan. A low area was central over Lake Superior and a secondary low over Nebraska. The pressure over the States where these thunderstorms occurred was about 30.0 inches, and the temperature in the seventies. The thunderstorm conditions were feeble and the rainfall light.

22d.—The low area moved eastward and was central over the St. Lawrence Valley at 8 a. m. with thunderstorms located in Pennsylvania, New York, and New England during the afternoon and late in the evening. Local thunderstorms were reported in Michigan, Illinois, and Iowa. The storm in New York and some portions of New England was severe, and heavy rain and vivid lightning characterized the storm in southeastern New York. The storms occurring in the East were on the southeast quadrant of the low, while those in the West were on the southwest, and the latter were local in character.

23d.—Local thunderstorms were reported from the Atlantic coast west to Wisconsin, but were very few and were heat storms.

24th.—Thunderstorms were reported in western New York and Pennsylvania, in Ohio, Michigan, and Wisconsin, and were heat storms, as the conditions from the intense heat were very favorable for the formation of these storms. This was during the height of the hot wave, and thunderstorm conditions were present on each of the days of this heated term to a more or less extent. A remarkable circumstance is reported in Ohio during the afternoon—the thunderstorms began on the east border of the State, and spread west from 4 p. m. to 8 p. m., the progression being well defined. The storm in Michigan began in the extreme southwest portion and moved east, with heavy rain and destructive lightning. A low area was moving in from the west and was central at St. Vincent at 8 a. m.

25th.—The low area was central at 8 a. m. over Lake Superior, with the pressure below the normal throughout the Lake region. The heat wave still remains nearly stationary in the entire district, the thermal line of 80° covering a larger portion of the territory. These conditions make it very favorable for the formation of local thunderstorms on the southeast quadrant of the low area, and thunderstorms are reported from Indiana and southeastern Michigan east to the Atlantic coast. The thunderstorms occurred in the forenoon in New York and New England, and local storms in the afternoon in southern New England, Michigan, Ohio, and Indiana.

26th—The heat wave has advanced to the east, and heat thunderstorms are reported from all sections, with no definite movement, the individual storms traveling but a short distance when they appear to die out. These storms occurred during the forenoon and afternoon, moved in all directions, were plainly indicated on the a. m. weather chart, and were to be anticipated from the intense heat which prevailed at this period. None of these storms had a progressive motion, but disappeared soon after their formation.

27th.—The low area moved south over Kansas, with a central pressure of 29.8 inches. The heat wave has moved slowly eastward, with local thunderstorms from New York west to Wisconsin. These storms were accompanied by heavy electrical discharges and heavy rainfall; there was no progressive motion noted in them.

28th.—The low area has moved over the St. Lawrence Valley during the day. Thunderstorms were reported late in the afternoon and in the evening in New England, New York, Michigan, Indiana, Illinois, Missouri, and Wisconsin. The storms in New England covered the whole district and have a distinct easterly trend, being on the southeast quadrant of the low area, while those of the West, on the southwest quadrant of the low area, were scattered and local in character, and had no general movement.

29th.—The low area was central over the St. Lawrence Valley, and the hot wave extended from the Lake region to the south Atlantic coast, with thunderstorm conditions reported from all districts, the storms being more severe along the Ohio Valley and northeast into New England. These storms occurred from 2 p. m. to 11 p. m., and were quite severe, accompanied by heavy rainfall in most cases. The storms occurred almost simultaneously throughout the district, and had no regular progressive motion.

30th.—Local storms were reported from along the Ohio River and in Pennsylvania and New Jersey, with one storm reported from New York. The low area has moved off the coast and a high area is central over Wisconsin and Michigan, with falling temperature.

31st.—A few local storms are reported in Wisconsin, Missouri, and New Jersey. The conditions were very feeble, and the storms did not travel over an extended territory. A low area was central over Lake Superior, with a slow eastward movement.

August, 1892.

1st.—A pressure of 30.0 inches covered most of the district this morning, and the temperature was nearly normal. A rain belt covered the majority of the territory and thunderstorms were developed in Illinois early in the morning along the Mississippi River; the storm was reported at Chicago at 12.57 p. m., and in Michigan from 1 p. m. to 5 p. m. in the State, and at 8.16 p. m. at Detroit, where the eastward movement appeared to have ceased. The second line of storms moved along the Ohio River; was at Springfield, Ill., 9.49 a. m., Indianapolis, Ind., at 5.21 p. m., and passed southeast into southern Ohio. A local storm occurred at Columbus, Ohio, at 12.13 p. m. The rainfall at the latter place was very heavy. The progression of this belt ceased in southern Ohio.

2d.—Local thunderstorms were reported at Baltimore, Md., and in southern New Jersey during the afternoon.

3d.—With a pressure of 30.0 inches and a temperature of 70° covering the district, with a rain belt confined to the lower Lake region and New England, thunderstorms were reported in northwestern Indiana and southwestern Michigan at 5 p. m. and moved east, reaching Detroit, Mich., at 8.10 p. m., where the progress east appears to have ceased for the night. Local thunderstorms were reported in Ohio. A low area began forming late in the afternoon and appeared to be concentrating over the St. Lawrence Valley.

4th.—The low area was central at 8 a. m. over the St. Lawrence Valley, and the thunderstorm belt which formed in northern Indiana, Ohio, and southern Michigan on the 3d was found in New York and New England, with local thunderstorms in eastern Pennsylvania. This belt appeared about 3 p. m., and covered the above-named States, and there appears a general easterly movement inclining slightly towards the northeast.

5th.—Although a low area was central over Lake Superior at 8 a. m., it is considered that the thunderstorms that occurred in Wisconsin from 5 a. m. to 7 a. m., in Illinois from 3 p. m. to 10 p. m., and along the Atlantic coast from noon until 5 p. m. were heat thunderstorms and not due to the location of the low area. The temperature was on the increase and the pressure nearly normal throughout the district, and local causes evidently entered to a large degree into the formation of the thunderstorm conditions. This appears to be justified by the fact that a belt of thunderstorms is formed on the following day in New York, and the predominating cause was indicated by the heat of the afternoon. The low area contributed to the formation of the conditions, but the initial force appears to proceed from the increasing temperature.

6th.—A small belt of thunderstorms appears late in the afternoon in northern New York and New England, and are probably a portion of the same belt which was reported in the West on the 5th. Four local storms are reported in Missouri, but the conditions were very feeble, and soon disappeared.

7th.—A local thunderstorm was reported at St. Louis, Mo., at 2.25 a. m. and lasted until 2.50 a. m., with heavy rainfall; this storm was again reported in eastern Illinois late in the afternoon, indicating that thunderstorm conditions were present, but not strong enough to develop a general storm.

8th.—Thunderstorms were reported during the morning in Iowa, Wisconsin, Michigan, and Ohio. Those in Wisconsin illustrate a clear type of regular progression of heavy thunderstorms with uniform velocity over an extended track. This belt was first reported in St. Croix County, on the west border of Wisconsin, at 1.40 a. m., and traveled eastward at the rate of 47 miles per hour, and reached Manitowoc County, on the eastern border of the State, a distance of 236 miles, at 7 a. m. It was nine times observed in regular succession across the State, and each moment of arrival was in regular cadence to establish the eastward movement of 47 miles per hour. This storm was reported in central Michigan at 1.45 p. m., and reached the eastern border late in the afternoon, with greatly diminished force, simply indicating that the thunderstorm conditions were present but feeble.

9th.—With a low area extending from the St. Lawrence Valley to Lake Superior, thunderstorms were reported in the morning and afternoon in New York, New England, New Jersey, Ohio, Michigan, Indiana, Illinois, Missouri, and Wisconsin. A clear type of the progressive thunderstorm is exhibited in a series of thunderstorms which occurred during the afternoon in Michigan. The thunderstorms began about 3 p. m. in the extreme southwestern portion and moved northeast across the State and passed out at 6 p. m. The storms in Wisconsin and contiguous States occurred later than did those in the Eastern States. The storms in New York and New England were attended by heavy rain and vivid lightning.

10th.—A low area, central pressure 29.8 inches, covered northern Michigan at 8 a. m., with a hot wave on the southeast quadrant, extending along the south Atlantic coast. Thunderstorm conditions began to develop about 1 p. m. in Missouri and Illinois; at 2.30 p. m. in northern Indiana and southern Michigan, and from 2 p. m. to 10 p. m. in Pennsylvania, New York, New Jersey, and New England. These latter storms were evidently heat storms, as they occurred throughout the district simultaneously and moved from all points of the compass. A series of thunderstorms began in southwestern Michigan about 1 p. m., and moved regularly northeast, reaching Port Huron, Mich., at 4 p. m., and was regularly observed at seven stations in the path during its progress.

11th.—The low area moved east over the St. Lawrence Valley, with the hot wave lying stationary on the Atlantic coast. Scattered thunderstorms were reported during the forenoon in Missouri, Illinois, and Ohio. In Pennsylvania, New Jersey, New York, and New England heavy thunderstorms were reported from 1 p. m. to 10 p. m. The main feature of these storms was the presence of the hot wave over this district, which assisted materially in the formation of the thunderstorm conditions. As is characteristic of heat thunderstorms there was no regular eastward movement, each storm appearing to take an individual path and die out after traveling a short distance.

12th.—Local thunderstorms occurred in Massachusetts, Connecticut, and Rhode Island during the afternoon, and there does not appear any progressive motion.

No storms of note are reported from the 12th until the 18th.

18th.—A low area was central at 8 a. m. over Lake Superior, moving east. A thunderstorm belt was developed at St. Louis, Mo., at 2.20 p. m., was reported twice in Illinois, and reached Chicago, Ill., at 10.08 p. m. Several light thunderstorms were reported in western Michigan from 8 p. m. to 10 p. m., indicating the presence of the thunderstorm belt moving east.

19th.—The low area moved over the St. Lawrence Valley and moved out during the day; a high was central over Minnesota, with a pressure throughout the district of 30.05 inches, and the temperature about 70°. Thunderstorms occurred from 6.10 a. m. to 11.50 a. m. in Michigan and Ohio, and in the afternoon in Pennsylvania, New York, and New England. A local storm occurred in the afternoon in Indiana. These storms had a general easterly movement, except in New England, where they appeared to come from the northwest and move southeast. These latter storms appear to be largely affected by local causes.

20th.—Thunderstorm conditions were reported in New England, Iowa, and Missouri. They were local in character and the conditions feeble.

21st.—Thunderstorm conditions were reported east of Cincinnati, Ohio, along the river, and in eastern Pennsylvania and New Jersey in the afternoon from 1 p. m. to 2.30 p. m. These storms were entirely local in character.

23d.—Local thunderstorm conditions were present during the afternoon in western Missouri. Rainfall light and the thunderstorm conditions feeble.

24th.—During the night of the 23d–24th a low area moved over Missouri and was central near St. Louis, Mo., at 8 a. m., and extended northeast. Thunderstorm conditions were reported at Red Wing, Minn., at 11.45 a. m., but were not reported to the east in Wisconsin; at St. Louis, Mo., at 11.05 a. m., Springfield at 5.23 p. m., Cairo, Ill., at 3.22 p. m., Cincinnati, Ohio, at 10.50 p. m., Columbus, Ohio, at 6.41 p. m., Sandusky, Ohio, at 8.25 p. m., and in Michigan from noon until midnight in different portions of the State. Three local storms were reported in New York.

25th.—The thunderstorm belt of the 24th moved east and was found on this date during the afternoon and evening in New York, Pennsylvania, New Jersey, and New England, with heavy rain in the different localities, and the thunderstorms severe. The general movement of these storms was from the west to east, although in the mountains of Pennsylvania their movement was diversified.

This is the last general thunderstorm condition that was reported during the season, which closed August 31, 1892. A few local storms occurred but were not of sufficient importance to warrant charting.

INVESTIGATION OF THUNDERSTORMS IN NEW ENGLAND, BY MR. ROBERT DeC. WARD, CAMBRIDGE, MASS.

The object of this investigation being "to gather material to be utilized in the study of these storms and the attending atmospheric conditions, with a view to predicting the occurrence of this class of storms for special localities in time to make the forecast of value to agricultural interests," particular attention has been paid to the verifications of the Washington and Boston forecasts during the summer of 1892 as far as the prediction of thunderstorms is concerned. In obtaining the percentages of verification the forecasts have been considered fully or partly verified when *rain*, *showers*, *local showers*, *showers accompanied by thunder*, *thunder showers*, or *thunderstorms*, were predicted for the region, or for some part of the region, where thunder showers fell, and for the time in which they fell.

The thunderstorms have been divided into two classes, (1) those which showed distinct progression when charted, and (2) those which did not move but appeared only as scattering reports. In obtaining the verifications of the forecasts only those storms have been considered which moved, as this is the only class which is likely to do damage, and is also the only class of which warning that the storm is on its way may be given by telegraph or by telephone, and whose conditions of occurrence therefore need special attention. The thunderstorms that do not show movement are usually very limited in extent, and are generally little more than thunder associated with light showers. These classes may be further subdivided according to the conditions under which the storms occur, and in this subdivision the writer recommends, with one change, the classification* given by Prof. W. M. Davis, who says:

> There appear to be four classes of summer thunderstorms, apart from those nondescripts whose features are lost in the far-reaching clouds of a general storm. The first class are those of local origin on quiet, hot, anticyclonic days, their action suggesting that they are merely overgrown convectional movements. * * * These are less common than the others. A second class includes those which spring up in the warm southerly winds southeast of a cyclonic center, and whose convectional overturning is therefore due in part to imported heat. * * * Such storms are also relatively rare. The third class includes the largest of our summer thunderstorms. These seem to be formed where the warm southerly winds are most nearly contrasted with the cooler westerlies that follow them. The storm forms along the line between the two and advances obliquely, broadside across country. * * * The fourth class of thunderstorms contains those which arise in the westerly winds, southwest of a cyclonic center, and whose convectional overturning is due as much to the importation of cool air aloft as to its warming on the ground below.

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*Annals of the Astronomical Observatory of Harvard College, Vol. XXI, Part II, pp. 131–132.

The change recommended by the present writer is the addition of a fifth class, to include "those nondescripts whose features are lost in the far-reaching clouds of a general storm." The characteristics of thunderstorms which occur under such conditions, in a general rain, are sufficiently distinct to warrant their being put in a definite class by themselves. The storm of May 3–4 may be taken as a good example of this proposed fifth class. These storms are seldom severe or destructive; they are not distinguished by marked changes in wind direction, although the squall-wind is generally noted at a few stations; hail seldom falls; the temperature is usually nearly stationary, and the rain is apt to continue after the thunderstorm itself has passed on, the thunder and lightning generally being accompanied by a somewhat heavier rainfall than is noted before or after the thunderstorm proper.

May.—During May thunderstorms were reported on the 2d, 3d, 4th, 9th, 11th, 12th, 16th, 17th, 26th, 27th, and 30th, but on three days only did the storms have distinct progression, viz., on the 3d–4th, 26th, and 27th. These latter, which all occurred in general rains, were predicted in the Washington and Boston forecasts both at 8 p. m. of the days previous and at 8 a. m. of the days of occurrence. They occurred southeast of the cyclonic centers on those days.

June.—In order to summarize the thunderstorms and forecasts in June as briefly as possible, Table I has been prepared. The first column gives the day of the month; in the second is a statement whether or not any observers reported, and if they did so the number of reports received is given; the third column states whether or not the thunderstorms had progression; the fourth gives the time, and the fifth the place of occurrence; in the sixth the intensity of the storms is noted (moderate, severe, violent); in the seventh column are the Washington, and the eighth the Boston forecasts, so much of them as relates to precipitation.

It appears from Table I that thunderstorms were reported on every day except the 4th, 5th, 7th, 8th, 10th, and 11th, that is, on twenty-four days. On thirteen days the storms had distinct movement; on the remaining eleven days there were generally very few reports and no progression could be made out, the records being scattered and not agreeing as to times of rain beginning and loudest thunder. As regards the verification of the forecasts the following results were obtained. The Boston forecasts not including Connecticut, the forecasts made for June 18, on which day a thunderstorm occurred in that State only, have not been considered. Taking the twelve remaining days on which progressive thunderstorms occurred, it is seen that the Washington 8 p. m. forecasts of the evenings previous were verified fully or partly in six, and were wrong in six cases, and the corresponding Boston forecasts were verified in nine and were wrong in three cases. Of the 8 a. m. forecasts on the thunderstorm days, the Washington forecasts were right in eight and failed in four cases; the Boston forecasts were verified in ten and were wrong in two cases. On the 2d the Washington 8 a. m. forecast has been considered wrong, as it predicted local rains in the evening, which means after 8 p. m., and on the 16th the Boston 8 a. m. forecast has been considered right, because it predicted showers on Friday the 17th, which began as a forecast day at 8 p. m. of the 16th.

It appears, therefore, that warning was given of the thunderstorms of June (either as *thunderstorms* or as *showers*) in the local forecasts issued at 8 p. m. of the days previous or at 8 a. m. of the same day, in ten cases, leaving two cases where no warning of any kind was given. In four cases *thunder showers* were predicted at 8 p. m. of the days previous, and in three more cases they were predicted at 8 a. m. of the days on which the thunderstorms occurred, and on three other days *showers* were predicted. There seems to have been no attempt made at Washington to predict *thunderstorms* as such, as in only one case was a thunderstorm successfully predicted, but as several of the display stations in New England receive the Washington forecasts it has been thought best to obtain the verifications of the Washington in the same way as in the case of the local forecasts. Every forecast of *thunderstorms*, *thunder showers*, or *showers probably accompanied by thunder* made at Boston during the month was verified.

As regards the conditions under which the thunderstorms of this month occurred, an examination of the 8 a. m. maps of the thirteen days on which progressive storms were noted brings out the following facts: On seven days the cyclonic area was over the Lakes; on two over the Gulf of St. Lawrence; on two over New England; on one over the Lower St. Lawrence, and on one day anticyclonic conditions prevailed, with pressure above the normal. The most violent thunderstorms occurred on the 14th and 17th, both of which days were marked by trough-shaped isobars to the southwest of the cyclonic center. The main features of the maps on these days are the general high temperatures over New England, being considerably above the normal in most cases; the occurrence of local showers or thunderstorms in the Lake region during the preceding twelve hours; conditions favorable for showers over New England during the following twelve hours; southerly or westerly winds; a cool wave south of the Lakes, and indications of a secondary depression over or to the west of New England in some cases. The main features of the 8 p. m. maps of the evenings previous are in general similar to those just enumerated, the distinguishing characteristics, in addition to these, being the position of the cyclonic center farther to the west in most cases, and the general rise of temperature over New England since the last observation.

Of the seventeen days in June on which no progressive thunderstorms occurred, ten had a pressure near or above normal, generally clear or fair and mostly cool, anticyclonic weather; four had cyclonic centers over the Lakes, the Gulf of St. Lawrence, or New England, with general rains or showers over the district, accompanied by thunder at a number of stations, but bringing no progressive thunderstorms, and on three days the pressure was near or above normal, with no definite center, and showers, accompanied by thunder at some stations, fell in parts of New England.

July.—It is seen from Table II that thunderstorms were reported during July on every day but the 1st, 4th, 7th, 16th, 17th, 20th, 21st, 27th, and 30th, that is, on twenty-two days. The thunderstorms showed distinct progression on nine days only; on the remaining thirteen days there were generally few reports, five days giving but one report on each day, one day giving two, and one day three reports, and the other six days bringing scattered reports of very moderate storms. Considering again, as in the case of June, only the progressive storms, it appears that the Washington 8 p. m. forecasts of the days previous to the occurrence of the thunderstorms were fully or partly verified in six cases, and were not verified in three cases, and the corresponding Boston forecasts were fully or partly verified in six, and wrong in three cases. Of the 8 a. m. forecasts on the nine days during which the thunderstorms occurred, the Washington were fully or partly verified in seven and not verified in two cases; the corresponding Boston forecasts were verified in eight cases, and not verified in one case. There being no 8 a. m. forecasts on July 3, which was Sunday, the Saturday 8 p. m. forecast has been used in calculating the verifications.

From Table II it will be seen that warning was given of the *rain* of these nine days, either in the Boston 8 p. m. forecasts of the preceding days or in the 8 a. m. Boston forecasts on the thunderstorm days, in every case. *Thunder showers* were predicted in the Boston forecasts at 8 p. m. of the days previous in two cases, and at 8 a. m. of the storm days in two more cases, and in the remaining five cases *showers* or *rain* were predicted. The Washington forecasts also gave warnings, either of *thunder showers* or of *rain*, in every case, when both 8 a. m. and 8 p. m. forecasts are reckoned. The Boston forecasts predicted no thunderstorms when such storms did not occur. The Washington forecasts predicted them in one case when they did not occur.

The 8 a. m. weather maps of the thunderstorm days show the following characteristics as to pressure: Cyclonic centers over the Lower St. Lawrence in three cases; over the Upper Lakes in two cases; over the Lower Lakes in two cases; over the Gulf of St. Lawrence in one case, and in the remaining case there was no well-defined center of low pressure. The further features were high temperatures over New England, in some cases unusually high; showers during the preceding twelve hours in the Lake regions, and generally a cool wave following over the Lakes or west of them. There were thirteen days on which thunderstorms were reported and showed no movement. These days were generally characterized by anticyclonic conditions of weather, with pressure above the normal. Two of them had moderate cyclonic areas over the Lakes or the Gulf of St. Lawrence, with high temperatures over New England, and it is to be noted that both of these days brought several reports of thunderstorms, though no movement can be made out. The no-thunderstorm days show either anticyclonic conditions or cyclonic areas over the Lower St. Lawrence or over the Gulf of St. Lawrence. In the latter cases clearing, cooler weather had already set in over New England, and the forecasts were for fair weather. The small number of distinct thunderstorms during July was evidently due to the fact that the anticyclones of the month were more marked and of longer duration than the cyclones, and, although they were less in number than the latter, they controlled the weather during the greater part of the month.

August.—During the month of August, as will be seen from Table III, thunderstorms were reported on all days but the following: 1st, 2d, 7th, 8th, 15th, 16th, 17th, 18th, 22d, 23d, 24th, 28th, 29th, and 30th. They were therefore recorded on seventeen days during the month. On nine of these days they showed progression across country, viz., on the 4th, 5th, 6th, 9th, 10th, 11th, 12th, 19th, and 25th. On the remaining eight days on which thunderstorms were reported they do not seem to have moved more than a very few miles, and no rain-front lines can be drawn. Of these days, two brought one report only, two brought two reports only, and of the remaining four days, two brought less than ten reports and one brought fifteen reports. It is seen from this that on those days when the thunderstorms did not have distinct progression the reports were very few in number. They were also scattered, and the local storms, often merely thunder without rain, to which they referred, were very moderate in character.

Coming now to the forecasts for the nine days with distinctly progressive thunderstorms, we find that the Washington and Boston 8 p. m. forecasts of the days previous were fully or partly verified in seven cases, and were not verified in two cases. Of the 8 a. m. Washington and Boston forecasts on the thunderstorm days, eight were fully or partly verified and one was not verified. It appears that warning was given of the precipitation on the nine thunderstorm days in the Boston forecasts in every case. *Thunderstorms or thunder showers*, or *showers with thunder*, were predicted in the Boston forecasts of the evenings preceding the nine distinct thunderstorm days in two cases, and in the morning forecasts of those days in three more cases, and in the remaining four cases *showers* or *local rains* were predicted, without mention of thunder. The Washington forecasts also covered the precipitation which came on these thunderstorm days in every case. The Boston forecasts gave no predictions of *thunderstorms*, *thunder showers* or *showers accompanied by thunder* which were not verified, fully or partly. The Washington forecasts predicted *thunder showers* for New England on two days only, and in each case the prediction was verified.

The nine days which brought distinctly progressive thunderstorms show the following characteristics as to pressure: Cyclonic centers over the Lower St. Lawrence in three cases; over the Gulf of St. Lawrence in two cases; over the Upper Lakes in one case; over the Lower Lakes in two cases, and off the New England coast in one case. The connection of thunderstorm occurrence with centers of low pressure is thus again clearly brought out, and also it is seen that the isobars were trough-shaped in several cases, notably on August 5th, 6th, and 19th, on all of which days severe thunderstorms occurred. The characteristics of these maps are, further, conditions favorable for rain and high temperatures over New England, and showers and lower temperatures in the Lake region during the preceding twelve hours. The maps of the eight days on which scattered thunderstorms or thunder were reported, but on which no distinct movement was noted, show the following characteristics: Pressure normal or above normal, and usually rising, temperatures considerably lower than on the distinct thunderstorm days (about 10°), with conditions favorable for showers, but closely followed by clearing weather in six cases and fair weather in two cases. The distinction between these two sets of maps is therefore quite clear. The maps of the remaining no-thunderstorm days show a striking similarity in their features, viz., pressure above the normal; temperatures lower than on thunderstorm days; fair, anticyclonic weather, and northerly or northeasterly winds. In a few cases there was a cyclonic center over the Gulf, moving off to the northeast. It is seen, therefore, that the conditions of thunderstorm occurrence were quite distinct through this month.

TABLE I.—*Summary of thunderstorms and forecasts for the New England States during June*, 1892.

Date.	Thunderstorm reports.	Had progression or not.	Time of occurrence.	Place of occurrence.	Intensity of storms.	Washington forecasts.	Boston forecasts.
1	Yes (1)	No	9-10 p. m	Me	Moderate	8 a. m. Fair weather, increasing cloudiness, and probably local showers Thursday night.	8 a. m. Fair.
						8 p. m. Fair weather, followed by cloudiness and local rains and probably thunderstorms.	8 p. m. Fair, followed during the late afternoon or night by showers, probably accompanied by thunder at places.
2	Yes (101)	Yes	1.30-6 p. m.	Vt., N. H., Mass., Conn.	Moderate	8 a. m. For Me., fair weather. For N. H., Vt., Mass., Conn., and R. I., increasing cloudiness and local rains this evening and Friday.	8 a. m. Continued warm and fair.
						8 p. m. Partly cloudy weather and showers Friday.	8 p. m. Showers, probably accompanied by thunder.
3	Yes (3)	No	p. m	N. H., Conn	Moderate	8 a. m. Some cloudiness and occasional showers.	8 a. m. Rain, probably followed by clearing to-night or Saturday morning.
						8 p. m. For Me., N. H., and Vt., generally fair. For Mass., R. I., and Conn., generally fair Saturday, except some cloudiness and local showers on the coast.	8 p. m. Fair, cooler.
4	No					8 a. m. Generally fair weather	8 a. m. Fair.
						8 p. m. Generally fair weather	8 p. m. Fair.
5	No					8 p. m. Partly cloudy weather and possibly a few showers, mostly along the coast Monday.	8 p. m. For R. I. and Mass., warmer and fair, except showers are probable in the afternoon. For Me., N. H., and Vt., warmer, partly cloudy and showers.
6	Yes (52)	Yes	1-5.30 p. m.	E. Mass., E. Conn., and R. I.	Moderate	8 a. m. For Me., N. H., and Vt., fair weather, except possibly showers in northwest portions to-night. For Mass., R. I., and Conn., fair weather.	8 a. m. Fair, preceded by thunder showers this afternoon.
						8 p. m. Generally clear weather	8 p. m. Fair and cooler.
7	No					8 a. m. Fair weather	8 a. m. Fair, cooler.
						8 p. m. Fair weather	8 p. m. Fair, slightly warmer.
8	No					8 a. m. Generally fair weather	8 a. m. Fair, warmer.
						8 p. m. Me., N. H., Vt., cloudiness and showers. Mass., R. I., Conn., cloudiness and scattered showers.	8 p. m. Fair, warmer.
9	Yes (52)	No	p. m	S. and SE. Mass., N. Conn., R. I.	Moderate	8 a. m. Partly cloudy and showers	8 a. m. Cloudy and showers.
						8 p. m. Partly cloudy and showers	8 p. m. Partly cloudy and showers.
10	No					8 a. m. Some cloudiness followed by generally clear weather and possibly preceded by showers along the coast from Nantucket to Sandy Hook.	8 a. m. Fair, cooler.
						8 p. m. Generally fair	8 p. m. Fair.

11	No					8 a. m. Fair	8 a. m. Fair, warmer.
						8 p. m. Fair	8 p. m. Fair, warmer.
12	Yes (1)	No	3-5 p. m	Vt	Moderate	8 p. m. Continued warm and fair	8 p. m. Fair, except local thunder showers during the afternoon.
13	Yes (15)	Yes	6-7 a. m., 4-6 p. m.	E. Me., Vt., Mass	Moderate	8 a. m. Continued very warm and clear weather	8 a. m. R. I. and Mass., fair, except local thunder showers Tuesday afternoon. Me., N. H., Vt., fair, except local thunder showers.
						8 p. m. Fair weather	8 p. m. Fair, except local thunder showers in the afternoon.
14	Yes (218)	Yes	12 m-9 p. m.	Me., N. H., Vt., Mass., R. I., and Conn.	Violent; much damage.	8 a. m. Continued fair; possibly local showers	8 a. m. Fair, followed by thunder showers to-night or Wednesday.
						8 p. m. Cooler, fair weather, followed by showers Wednesday night.	8 p. m. Much cooler, clearing and fair weather.
15	Yes (1)	No	1 a. m	R. I	Moderate	8 a. m. Fair	8 a. m. Fair.
						8 p. m. Clear	8 p. m. Fair.
16	Yes (35)	Yes	6.30-10 p. m.	N. Vt., N. H., Me., Mass., and Conn.	Moderate	8 a. m. Me., N. H., Vt., local showers, fair Friday. Mass., R. I., and Conn., fair, except showers in western Mass.	8 a. m. Fair to-day; partly cloudy and showers Friday.
						8 p. m. Me., fair, except showers in western portion. N. H., showers, followed by clearing weather. Vt., showers to-night, clearing Friday. Mass., R. I., and Conn., light showers, clearing during the day.	8 p. m. Partly cloudy and showers.
17	Yes (186)	Yes	10 a. m.-6 p. m.	Me. (except in N.), N. H. (except in N.), Vt., Mass., R. I., and Conn.	Severe; considerable damage.	8 a. m. Me., N. H., and Vt., generally fair on Saturday. Mass., R. I., and Conn., local showers, followed by clearing cooler weather during Saturday.	8 a. m. Showers during the afternoon.
						8 p. m. Fair	8 p. m. Fair.
18	Yes (32)	Yes	1.30-5.30 a. m.	Conn	Moderate	8 a. m. Fair	8 a. m. Fair.
						8 p. m. Me., N. H., Vt., and Mass., fair. R. I. and Conn., generally fair, except showers on the coast.	8 p. m. Fair.
19	Yes (3)	No	p. m.	N. H. and Conn	Moderate	8 p. m. Me., N. H., and Vt., showers. Mass., R. I., and Conn., light rains, clearing during the day.	8 p. m. Partly cloudy weather and showers, probably accompanied by thunder at places.
20	Yes (7)	No	Early a. m. and p. m.	N. H., Mass., and R. I.	Moderate	8 a. m. Me., N. H., and Vt., showers, followed by clearing weather. Mass., probably fair. R. I. and Conn., fair.	8 a. m. Partly cloudy, showers this p. m. and again Tuesday p. m.
						8 p. m. Me., N. H., and Vt., showers. Mass., R. I., and Conn., generally fair.	8 p. m. Mass. and R. I., fair followed by showers. Me., N. H., and Vt., partly cloudy and showers.
21	Yes (59)	Yes	3-5 p. m	Central and SE. Mass., N. and E. Conn., and R. I.	Moderate	8 a. m. Me., N. H., and Vt., showers, followed by clearing weather. Mass., generally fair. R. I. and Conn., fair.	8 a. m. Partly cloudy and local thunder showers this afternoon, general thunder showers Wednesday.
						8 p. m. Me., N. H., and Vt., showers. Mass., showers. R. I. and Conn., local rains.	8 p. m. Fair weather, followed during the afternoon by thunder showers.
22	Yes (22)	Yes	8-10 a. m	Conn., Me., N. H., and Vt.	Moderate	8 a. m. Me., N. H., and Vt., showers. Mass., R. I., and Conn., local rains.	8 a. m. Showers.
						8 p. m. Generally fair	8 p. m. Fair, cooler; rain Thursday night or Friday.
23	Yes (77)	Yes	1-5 p. m	Mass., Conn., Me., N. H., and Vt.	Moderate	8 a. m. Showers	8 a. m. Light rains.
						8 p. m. Local showers on the coast; generally fair in the interior.	8 p. m. Showers, followed by clearing weather.

TABLE I.—*Summary of thunderstorms and forecasts for the New England States during June*, 1892—Continued.

Date.	Thunderstorm reports.	Had progression or not.	Time of occurrence.	Place of occurrence.	Intensity of storms.	Washington forecasts.	Boston forecasts.
24	Yes... (24)	No....	6-8 p. m	N. H., Vt., Me., and Conn.	Moderate.......	8 a. m. Me. and N. H., showers. Vt., fair. Mass., R. I., and Conn., fair on Saturday, preceded by showers on the coast.	8 a. m. Generally fair.
						8 p. m. Showers, followed by fair..................	8 p. m. R. I. and Mass., partly cloudy and showers. Vt., N.H., and Me., showers.
25	Yes... (49)	Yes...	12 m.-4 p.m.	NE. Mass. and S. N. H.	Moderate.......	8 a. m. Me., N. H., and Vt., fair Sunday. Mass., R. I., and Conn., showers to-day, fair Sunday.	8 a. m. Showers to-day, fair Sunday and Monday.
						8 p. m. Me. and N. H., showers, followed by fair weather. Vt., Mass., R. I., and Conn., fair.	8 p. m. Fair, except local showers.
26	Yes... (23)	No....	2-5 p. m	Vt., S. N. H., and Mass.	Moderate.......	8 p. m. Increasing cloudiness, followed by showers during the afternoon or night.	8 p. m. Showers.
27	Yes... (20)	No....	5-8 p. m	Vt., N.H., W. Mass., and SW. Conn.	Moderate.......	8 a. m. Threatening weather and rain, probably clearing during Tuesday forenoon.	8 a. m. Cloudiness and rain.
						8 p. m. Me., N.H., Mass., R. I., and Conn., showers. Vt., rain.	8 p. m. Rain.
28	Yes... (12)	No....	Early a. m..	Me., N. H., Mass., and R. I.	Moderate.......	8 a. m. Showers	8 a. m. Showers to-day; fair Wednesday.
						8 p. m. Generally fair	8 p. m. Fair.
29	Yes... (47)	Yes...	6-7 p. m., 10-12 p. m.	Vt., N. H., and Mass.	Moderate.......	8 a. m. Me. and N. H., fair, probably followed by local showers Thursday night. Vt., local showers. Mass., R. I., and Conn., fair, probably followed by local showers by Thursday night.	8 a. m. Fair to-day; Thursday fair, except local showers during the afternoon.
						8 p. m. Me., N. H., and Vt., generally cloudy, with light showers. Mass., R. I., and Conn., probably fair Thursday, followed by light showers during the afternoon or night.	8 p. m. Mass. and R. I., fair, except during the afternoon. Vt. and N. H., showers. Me., fair, followed by showers.
30	Yes... (165)	Yes...	1-5 p. m.	Vt., N. H., S. Me., Mass., and Conn.	Moderate; generally severe in Conn.	8 a. m. Showers..................................	8 a. m. Rain.

TABLE II.—*Summary of thunderstorms and forecasts for the New England States during July,* 1892.

Date.	Thunderstorm reports.	Had progression or not.	Time of occurrence.	Place of occurrence.	Intensity of storms.	Washington forecasts.	Boston forecasts.
1	No....	....	....	....	....	8 a. m. Me., N. H., and Vt., generally fair. Mass., R. I., and Conn., local showers. 8 p. m. Me. and N. H., fair. Vt., fair; rain by Sunday morning. Mass., fair. R. I. and Conn., fair; local showers on coast.	8 a. m. Fair. 8 p. m. Fair.
2	Yes... (2)	No....	p. m	Vt	Thunder only ..	8 a. m. Fair; showers on Sunday.................. 8 p. m. Increasing cloudiness and rain............	8 a. m. Fair. 8 p. m. Increasing cloudiness followed by rain.
3	Yes... (137)	Yes...	12·30–6 p. m..	Me., N. H., Vt., Mass., R. I., and Conn.	Severe..........	8 p. m. Showers; clearing during Monday.........	8 p. m. Fair.
4	No....	....	....	....	....	8 p. m. Fair	8 p. m Fair.
5	Yes... (1)	No....	a. m	Vt	Thunder only ..	8 a. m. Fair..................................... 8 p. m. Fair	8 a. m. Fair. 8 p. m. Fair.
	Yes... (28)	No....	....	Vt., N. H., Mass., and R.I.	Moderate.	8 a. m. Fair..................................... 8 p. m. Fair	8 a. m. Fair. 8 p. m. Fair.
7	No....	....	....	....	....	8 a. m. Fair..................................... 8 p. m. Fair	8 a. m. Fair. 8 p. m. Fair.
8	Yes... (59)	No....	p. m........	S. N. H., Vt., Mass., Conn., and R. I.	Moderate.......	8 a. m. Fair..................................... 8 p. m. Me., N. H., and Vt., fair. Mass., R. I., and Conn., local showers to-night.	8 a. m. Fair. 8 p. m. Fair, except local showers during the afternoon.
9	Yes... (39)	No....	a. m. and p. m.	Me., Vt., N. H., and W. Conn.	Moderate.......	8 a. m. Me., N. H., and Vt., fair, preceded by local showers in southern portions. Mass., R. I., and Conn., generally fair Sunday, probably showers Sunday evening or night. 8 p. m. Local showers, followed by clearing weather.	8 a. m. Fair, except scattered local showers. 8 p. m. Showers.
10	Yes... (1)	No....	p. m	Vt	Moderate.......	8 p. m. Fair	8 p. m. Fair.
11	Yes... (1)	No....	p. m	Vt	Thunder only ..	8 a. m. Fair..................................... 8 p. m. Me., N. H., Vt., R. I., and Mass., fair. Conn., fair, except light local showers on the coast.	8 a. m. Fair. 8 p. m. Fair.
12	Yes... (13)	No....	p. m	Vt., Mass., R.I., and Conn.	Moderate.......	8 a. m. Me., N. H., Vt., fair, local showers Wednesday afternoon or night. Mass., R. I., and Conn., fair. 8 p. m. Me., N. H., Vt., and Mass., fair, followed by local showers during the afternoon or night. R. I. and Conn., fair.	8 a. m. Fair, probably followed by showers Wednesday. 8 p. m. Fair, followed during the afternoon by local thunder showers.

TABLE II.—*Summary of thunderstorms and forecasts for the New England States during July,* 1892—Continued.

Date.	Thunderstorm reports.	Had progression or not.	Time of occurrence.	Place of occurrence.	Intensity of storms.	Washington forecasts.	Boston forecasts.
13	Yes... (128)	Yes...	2.30-7.30 p. m.	N. H., Vt., Mass., and Conn.	Moderate.......	8 a. m. Me., N. H., Vt., and Mass., local showers. R. I. and Conn., fair. 8 p. m. Showers, followed by clearing weather....	8 a. m. Fair, probably interrupted by local showers to-night or to-morrow. 8 p. m. Showers, followed by clearing weather.
14	Yes... (52)	Yes...	4-12 p. m ...	Me., N. H., Vt., E. Mass., N. Conn., and R. I.	Moderate.......	8 a. m. Fair..................................... 8 p. m. Fair....................................	8 a. m. Fair, except scattered local showers this afternoon and evening. 8 p. m. Fair.
15	Yes... (122)	Yes...	11.30 p. m.-4 a. m. of 16th.	S. Me., N. H., Vt., Mass., R. I., and Conn.	Severe till 12 p. m., then moderate.	8 a. m. Me. and N. H., increasing cloudiness, with showers during Friday night or Saturday. Vt., showers, followed by clearing weather. Mass., local showers, followed by clearing weather. R. I. and Conn., fair. 8 p. m. Showers and severe local storms	8 a. m. Mass. and R. I., fair to-day, followed by local showers to-night and to-morrow. N. H. and Vt., showers, probably beginning this afternoon. Thunderstorms are likely to accompany showers. 8 p. m. Showers.
16	No....	....	....	....	....	8 a. m. Fair.................................... 8 p. m. Fair....................................	8 a. m. Fair. 8 p. m. Fair.
17	No....	....	....	....	....	8 p. m. Fair	8 p. m. Fair.
18	Yes... (1)	No....	8.20 p. m....	Me	Moderate.......	8 a. m. Fair.................................... 8 p. m. Generally fair, probably followed by local showers in Vt.	8 a. m. Fair. 8 p. m. Fair, except local showers in Vt., N. H., and western Mass.
19	Yes... (3)	No....	a. m. and 2.30 p. m.	Me. and Vt..........	Thunder only ..	8 a. m. Increasing cloudiness, probably followed by local showers. 8 p. m. Local showers to-night, generally fair Wednesday.	8 a. m. Fair, except scattered local showers are probable to-night and to-morrow. 8 p. m. Local showers, followed by fair.
20	No....	....	....	....	....	8 a. m. Fair.................................... 8 p. m. Fair	8 a. m. Fair, except showers for the coast of northern Me. this afternoon. 8 p. m. Fair.
21	No....	....	....	....	....	8 a. m. Fair.................................... 8 p. m. Fair....................................	8 a. m. Fair. 8 p. m. Fair.
22	Yes... (22)	Yes...	2 p.m.-11.30 p. m.	S. Me., N. H., Vt., Mass., and Conn.	Moderate.......	8 a. m. Generally fair, preceded by light local showers in northern portion to-day or to-night. 8 p. m. Me., N. H., and Vt., clearing, generally fair. Mass., R. I., and Conn., occasional thunderstorms, but generally fair during the day.	8 a. m. Fair, except showers are likely this afternoon in parts of northern Me., N. H., and Vt. 8 p. m. Mass. and R. I., fair, except local thunder showers. Me., N. H., and Vt., generally fair.
23	Yes... (22)	No....	Early a. m. and p. m.	E. Me., Vt., SE. Mass., E. Conn., and R. I.	Moderate.......	8 a. m. Fair.................................... 8 p. m. Fair....................................	8 a. m. Fair. 8 p. m. Fair.
24	Yes... (14)	No....	Late p. m...	N. H., Vt., and Mass.	Moderate.......	8 p. m. Fair, probably followed by local thunderstorms during the afternoon or night.	8 p. m. Fair, except scattered local showers.

25	Yes... (78)	Yes...	2.30 a. m.-4.30 a. m., 2.30 p. m.-7 p. m.	Me., N. H., Vt., Mass., Conn., and R. I.	Moderate.......	8 a. m. Me., N. H., and Vt., fair, probably followed by local showers Tuesday or Tuesday night. Mass., R. I., and Conn., fair, with local showers in Mass. by Tuesday night. 8 p. m. Fair..	8 a. m. Fair, except occasional local showers and thunderstorms. 8 p. m. Generally fair.
26	Yes... (61)	Yes...	1 a. m.-3 a. m., 9 a. m. -10.30 a. m., p. m.	Me., N. H., Vt., Mass., R. I., and Conn.	Moderate.......	8 a. m. Me., N. H., and Vt., local showers. Mass., R. I., and Conn., generally fair. 8 p. m. Me., N. H., and Vt., fair. Mass., R. I., and Conn., generally fair, possibly local thunderstorms by Wednesday night.	8 a. m. Fair, occasional showers due to excessive heat. 8 p. m. Generally fair.
27	No....	....	....	....	....	8 a. m. Generally fair.............................. 8 p. m. Me. and N. H., fair. Vt., showers during the afternoon or night. Mass. and R. I., increasing cloudiness, with local thunderstorms during the afternoon or night.	8 a. m. Fair. 8 p. m. Fair, followed Thursday night or Friday by local thunder showers.
28	Yes... (140)	Yes...	4 p. m.-10 p. m.	N. H., Vt., Mass., Conn., and R. I.	Moderate.......	8 a. m. Me. and N. H., fair, except showers in N. H. and southern New England. Vt., local showers to-night or to-morrow. Mass., R. I., and Conn., local showers to-day or to-night. 8 p. m. Me., N. H., and Vt., local showers, except in eastern Me. fair weather. Mass., R. I., and Conn., increasing cloudiness, probably local showers Friday afternoon or night.	8 a. m. Fair, except showers are likely this afternoon and night in northern parts of Me., N. H., and Vt. 8 p. m. R. I., fair. Mass., Vt., and N. H., showers during the day. Me., showers during the afternoon.
29	Yes... (156)	Yes...	2 p. m.-11 p. m.	Me., N. H., Vt., Mass., R. I., and Conn.	Moderate generally, severe in places.	8 a. m. Increasing cloudiness, probably followed by local showers during Friday night or Saturday. 8 p. m. Me., N. H., and Vt., showers. Mass., R. I., and Conn., local rains.	8 a. m. Mass. and R. I., fair. Me., N. H., and Vt., fair, except local showers are likely this afternoon or night. 8 p. m. Clearing and fair weather, preceded by rain in Me.
30	No....	....	....	....	....	8 a. m. Me., N. H., and Vt., clearing to-day on the coast. Mass., R. I., and Conn., on Sunday fair weather. 8 p. m. Me., N. H., Vt., and Mass., fair. R. I. and Conn., fair, except local showers on the coast.	8 a. m. Fair, except showers to-day for coast sections. 8 p. m. Generally fair, except cloudiness and some rain on the extreme southern New England coast.
31	Yes... (1)	No....	p. m	Conn	Thunder only ..	8 p. m. Local showers to night....................	8 p. m. Mass., R. I., southern N. H., and southern Me., cloudy and some light rain. Vt., northern N. H., and northern Me., generally fair.

TABLE III.—*Summary of thunderstorms and forecasts for the New England States during August*, 1892.

Date.	Thunderstorm reports.	Had progression or not.	Time of occurrence.	Place of occurrence.	Intensity of storms.	Washington forecasts.	Boston forecasts.
1	No					8 a. m. Me., N. H., and Vt., showers on the coast to-day; fair to-night. Mass., R. I., and Conn., showers to-day; fair to-night. 8 p. m. Generally fair	8 a. m. Cloudy and unsettled, probably occasional rains along the coast. 8 p. m. Generally cloudy on the coast and partly cloudy in the interior, probably followed by light local rains during the night.
2	No					8 a. m. Me., N. H., and Vt., fair, followed in southern portions by showers to-night. Mass., R. I., and Conn., showers, followed by clearing weather. 8 p. m. Rain, followed by fair weather	8 a. m. Cloudy, probably light rains for the southern coast sections. 8 p. m. Continued rainy, probably followed by clearing during the afternoon or evening.
3	Yes (2)	No	p. m	Conn	Thunder only	8 a. m. Fair, preceded to-day by showers on the coast 8 p. m. Generally fair	8 a. m. Fair, preceded by coast showers to-day. 8 p. m. Fair.
4	Yes (70)	Yes	4-8.30 p. m.	Me., N. H., Vt., Mass.	Moderate	8 a. m. Fair, except showers in northern portion to-day or to-night. 8 p. m. Fair, except showers in N. H. and Vt. to-night.	8 a. m. Fair, except showers this afternoon or evening in northern parts of Me., N. H., and Vt. 8 p. m. Fair, preceded by local rains except in R. I.
5	Yes (67)	Yes	p. m	Me., N. H., Vt., Mass., R. I., and Conn.	Generally moderate, but severe in places.	8 a. m. Clearing to-day; fair to-night. 8 p. m. Showers in the northern portion and on the coast.	8 a. m. Generally fair. 8 p. m. Partly cloudy, followed during the afternoon by showers, probably attended by thunder.
6	Yes (51)	Yes	2-6 p. m	Me., N. H., Vt., Mass.	Severe	8 a. m. Showers in northern portion and on the coast to-day; clearing to-night. 8 p. m. Fair	8 a. m. Fair, preceded by showers to-day on the Maine coast. 8 p. m. Fair.
7	No					8 p. m. Fair	8 p. m. Fair.
8	No					8 a. m. Me., N. H., and Vt., fair, except showers to-night or Tuesday in northern portions. Mass., R. I., and Conn., fair, probably preceded to-day by showers on the coast. 8 p. m. Me., N. H., and Vt., fair, except showers in northern portions. Mass., R. I., and Conn., fair.	8 a. m. Fair, followed by increasing cloudiness Tuesday. 8 p. m. Fair, followed by thunder showers during the afternoon or evening.
9	Yes (108)	Yes	a. m. and p. m.	Me., N. H., Vt., Mass., R. I., and Conn.	Generally moderate.	8 a. m. Me., N. H., and Vt., showers, followed to-night by clearing weather. Mass., R. I., and Conn., fair. 8 p. m. Me., N. H., and Vt., fair Wednesday, followed by increasing cloudiness and rain Wednesday night or Thursday. Mass., R. I., and Conn., fair, preceded by showers to-night in eastern Mass.; rain Wednesday night or Thursday.	8 a. m. Fair, except local showers or thunderstorms are probable during the afternoon or night. 8 p. m. Partly cloudy weather and showers.

10	Yes (70)	Yes	3.30–5 a.m., p. m.	Me., N. H., Vt., Mass., R. I., and Conn.	Generally moderate; severe in Vt. and N. H.	8 a. m. Me., N. H., and Vt., fair, followed in northern portions by showers to-night or Thursday. Mass., R. I., and Conn., fair.	8 a. m. Continued fair weather, except thunderstorms and local showers are likely this afternoon and night.
						8 p. m. Showers	8 p. m. Showers.
11	Yes (108)	Yes	2–9 p. m	Me., N. H., Vt., Mass., R. I., and Conn.	Severe	8 a. m. Me., N. H., and Vt., thunder showers to-day and to-night. Mass., R. I., and Conn., thunder showers to-day, clearing to-night.	8 a. m. Continued fair, except thunderstorms and local showers are probable this afternoon or night.
						8 p. m. Me., N. H., and Vt., showers, followed by clearing by Friday night. Mass., R. I., and Conn., showers, clearing by Friday night.	8 p. m. Showers, followed by clearing during the afternoon and evening.
12	Yes (48)	Yes	12.30–2 a m., 5–7.3c p m.	Me., N. H., Vt., Mass., R. I., and Conn.	Violent	8 a. m. Me., N. H., and Vt., clearing to-day. Mass., R. I., and Conn., showers to-day, clearing to-night.	8 a. m. Fair, preceded to-day in coast and southern sections by showers.
						8 p. m. Me., N. H., Vt., rain, clearing by Saturday night. Mass., R. I., Conn., showers, followed by clearing Saturday.	8 p. m. Cloudy or partly cloudy, preceded by light rains in Me. and Vt.
13	Yes (7)	No	p. m	N. H., Mass., Conn., and R. I.	Very moderate.	8 a. m. Showers, clearing by Sunday	8 a. m. Fair, except showers are likely to-day for coast sections.
						8 p. m. Me., N. H., and Vt., fair, except showers in northern portions. Mass., R. I., and Conn., fair.	8 p. m. Fair, except local showers in parts of Vt., N. H., and Me.
14	Yes (2)	No	Early a. m.	Mass	Thunder only	8 p. m. Me., N. H., and Vt., fair, except showers in northern portions. Mass., R. I., and Conn., fair.	8 p. m. Fair.
15	No					8 a. m. Fair	8 a. m. Fair.
						8 p. m. Me., N. H., and Vt., fair, except showers in eastern Me. Mass., R. I., and Conn., fair.	8 p. m. Fair.
16	No					8 a. m. Fair	8 a. m. Fair.
						8 p. m. Fair	8 p. m. Fair.
17	No					8 a. m. Fair	8 a. m. Fair.
						8 p. m. Me., N. H, and Vt., fair, followed Thursday night by showers in northern portions. Mass., R. I., and Conn., fair.	8 p. m. Fair.
18	No					8 a. m. Me., N. H., Vt., fair, followed in northern portions by showers to-night or Friday. Mass., R. I., and Conn, fair.	8 a. m. Fair, except showers are likely in parts of Me., N. H., and Vt. Friday afternoon or night.
						8 p. m. Me., N. H., and Vt., fair, followed in northern N. H. and Vt. by showers. Mass., R. I., and Conn., fair, followed Friday night by showers in western Mass.	8 p. m. Fair, probably followed by showers during the afternoon or evening.
19	Yes (65)	Yes	p. m	N. Vt., S. N. H., N. Mass., and Conn.	Severe in Vt. and Mass.; elsewhere moderate.	8 a. m. Me., N. H., and Vt., showers in Me. Saturday and in N. H. and Vt. to-night. Mass., R. I., and Conn., increasing cloudiness and showers.	8 a. m. Fair, except showers may occur in northern sections to-night.
						8 p. m. Showers	8 p. m. Showers.
20	Yes (15)	No	Early p. m.	N. H., Vt., Mass., and Conn.	Moderate	8 a. m. Me., N. H., and Vt., showers to-day. Mass., R. I., and Conn., showers to-day; clearing in the interior to-night.	8 a. m. Cloudy, probably light rain for some of the coast sections to-day.
						8 p. m. Fair, preceded by showers on the coast to-night.	8 p. m. Generally fair.
21	Yes (1)	No	p. m	S. Conn	Thunder only	8 p. m. Fair	8 p. m. Fair.
22	No					8 a. m. Fair	8 a. m. Fair.
						8 p. m. Fair	8 p. m. Fair.

Date.	Thunderstorm reports.	Had progression or not.	Time of occurrence.	Place of occurrence.	Intensity of storms.	Washington forecasts.	Boston forecasts.
23	No					8 a. m. Me., N. H., and Vt., increasing cloudiness and showers in northern portions to-night or Wednesday. Mass., R. I., and Conn., fair.	8 a. m. Fair.
						8 p. m. Me., N. H., and Vt., increasing cloudiness; showers in northern portions by Wednesday night. Mass., R. I., and Conn., fair, except showers in western Mass.	8 p. m. Fair.
24	No					8 a. m. Me., N. H., and Vt., showers in northern portions to-day; showers Thursday. Mass., R. I., and Conn., showers in western Mass. to-day or to-night; showers Thursday.	8 a. m. Generally fair to-day, favorable to local rains to-night and to-morrow.
						8 p. m. Me., N. H., and Vt., showers and thunderstorms. Mass., R. I., and Conn., showers and probably thunderstorms.	8 p. m. Increasing cloudiness, followed by rain.
25	Yes (16)	Yes	9-10 p. m	Mass. and W. Conn.	Moderate	8 a. m. Me., N. H., and Vt., showers and probably thunderstorms to-day. Mass., R. I., and Conn., thunderstorms to-day; clearing Friday.	8 a. m. Rain, probably thunderstorms during the evening or night.
						8 p. m. Me., N. H., and Vt., showers, followed by clearing in northern portions. Mass., R. I., and Conn., showers.	8 p. m. Mass. and R. I., rain, followed during the day by clearing weather. Me., N. H., and Vt., rain.
26	Yes (8)	No	Early a. m.	Mass. and R. I.	Moderate	8 a. m. Me., N. H., and Vt., clearing in northern portions to-day, and in southern portions to-night. Mass., R. I., and Conn., clearing to-day or to-night.	8 a. m. Clearing during the evening or night.
						8 p. m. Me., N. H., and Vt., fair, preceded to-night by showers in N. H. and Vt. Mass., R. I., and Conn., showers.	8 p. m. Mass. and R. I., cloudy and some rain. Me., N. H., and Vt., local showers in Vt., but generally fair.
27	Yes (1)	No	p. m	Me	Moderate	8 a. m. Me., N. H., and Vt., fair in northern, showers in southern portions. Mass., R. I., and Conn., showers to-day, clearing to-night or Sunday morning.	8 a. m. Cloudy, threatening, rain along the coast, clearing to-night for southern sections.
						8 p. m. Me., N. H., and Vt., showers, followed by fair weather. Mass., R. I., and Conn., showers followed by clearing weather.	8 p. m. Clearing and fair weather, preceded by rain during the early morning in Me.
28	No					8 p. m. Fair	8 p. m. Fair.
29	No					8 a. m. Fair	8 a. m. Fair, probably rain by Tuesday night.
						8 p. m. Fair	8 p. m. Fair, except local showers during the afternoon or evening in Vt.

30	No					8 a. m. Me., N. H., Vt., fair, followed Wednesday by showers in northern portions. Mass., R. I., and Conn., fair. 8 p. m. Me., N. H., and Vt., showers by Wednesday night; showers in northern portion Wednesday. Mass., R. I., and Conn., showers and cooler by Wednesday night.	8 a. m. Unsettled, rain probably beginning during the evening or night. 8 p. m. Generally cloudy, followed during the evening or night by rain.
31	Yes (4)	No	p. m	SE. Mass., S. Conn., and R. I.	Moderate	8 a. m. Showers 8 p. m. Showers	8 a. m. Unsettled, probably light rains to-day and to-night. 8 p. m. Fair, preceded by showers in Me., N. H., and Vt.

CONCLUSION.

From the accompanying tables and summary the status of the Washington and Boston forecasts regarding the thunderstorms of the summer has been made clear, and in presenting this result the chief object of this report has been attained. It must be confessed that the interpretation of the verifications has been very liberal, but still the fact stands out quite plainly that the percentage of success was high. It was intended, at the beginning of the summer's work, to make arrangements for having telegraphic reports sent to Boston from a few stations on the western border of Massachusetts and Connecticut whenever a distinct thunderstorm passed over the observers there. The hope was that such a scheme, tried throughout one or two months, would show whether this is practicable on a larger scale, the object being to determine whether or not some such plan, systematically carried out, might not make more definite thunderstorm forecasts possible by the sending out of special telegrams from the Boston office, giving warning of approaching storms. This plan was not put into operation for several reasons, but the experience of the summer has shown that it would have been of little use. In the first place, if a thunderstorm passed over a single station, or even several stations on the western border, it would be difficult to tell whether it was going to extend so as to cover all, or a part, of New England, or was soon to fade away, traveling only a few miles. Secondly, the time consumed in sending the telegraphic reports to the Boston office and from there out again to other stations would be so long that the thunderstorm, if it were moving across country at the usual rate, would have reached most of the towns before the telegram from Boston could be received. This plan is therefore deemed impracticable.

Another plan, first suggested some twenty or more years ago, seems to have a good deal to recommend it. It is, briefly, this: Whenever any observers on the western borders of, in this case, Vermont, Massachusetts, and Connecticut, note the passage of a thunderstorm over their place of observation, they shall at once telegraph or telephone the fact to other places farther east, and that from these latter stations the warning should be sent on still farther east, and so on. At every place where such a warning is received, flags should be hoisted or whistles blown, according to some definite prearranged scheme, to inform the people of the fact that a thunderstorm is on its way. It is believed that this method would be the best one, and indeed the only practicable one, for giving distinct warning of approaching storms by telegraph or telephone. The advantages to be gained from it would be greatly increased if warnings could be received from stations in New York State whenever thunderstorms pass over them moving in an easterly direction. Such a plan, systematically arranged in the spring and carried out through the summer, would, it is believed, be of great benefit to farmers. One of the difficulties in making it successful is the lamentable lack of trained observers in New England. A trained observer can, in many cases, tell whether a thunderstorm at his place of observation is merely a local one, or is part of one of the larger disturbances, which often extend over several hundred miles and may be expected to travel across the districts north and south, as well as east of him. To give warning to stations farther east in *every* case where a thunderstorm passes over any place would very soon bring the whole scheme into ridicule.

Considering the success attained in the forecasts during the summer, it is believed that the first step to benefit agricultural interests at present should be towards a greater extension of the display stations of the New England Weather Service. The increase in the number of these stations during the past year has been very rapid, and at present the forecasts are scattered broadly over all the New England States, but the further extension of this work, by sending out more telegraphic and telephonic forecasts, and by the establishment of more display stations, would, it is evident, be of great and direct benefit, both in disseminating the forecasts in general, and the thunderstorm forecasts in particular. In this direction the Weather Bureau has a field of work which cannot fail to be productive of great good to the farmers of New England.

It has been seen, as was to have been expected, that the local forecasts made at Boston attained a somewhat higher degree of accuracy than those made at Washington. This, combined with the additional fact that the Boston forecasts are made and sent out from half an hour to an hour before the Washington forecasts are received at Boston, makes it plain that the interests of the Weather Service work in New England would be best furthered by the distribution of the local forecasts.

The majority of the voluntary observers kept faithful records throughout the summer, but their inexperience in such matters, which they frankly acknowledge, necessarily impairs the value of the reports. The latter serve well enough to determine the main facts of the extent and progression of the storm, and of the changes in wind direction and temperature, but the data as to amount of rainfall and direction of movement of the storms have generally been disregarded, on the ground that they are unreliable. The careful measurement of rainfall is a difficult task, and the crude means necessarily adopted by the observers make it plain that the amounts registered are in most cases too inaccurate for quotation. The rainfall records have, however, served very well to give a general idea of the amount of rain, whether heavy or light. As to direction of movement, the records differ very greatly, observers near together often giving exactly contrary directions. For this reason, and because the determination of the movement of a thunderstorm from each place of observation by itself is very difficult, this portion of the records has generally been disregarded. The space devoted to "Remarks" on the blanks was very small, but several observers made good use of it. The most noteworthy remarks have been quoted in the preceding pages, and some of them show careful and interested attention on the part of the observers to the storms to which they refer. The most valuable notes on the thunderstorms of the summer are those from Prof. W. M. Davis in connection with the storms of June 14 and 17, but many of the others, quoted in the descriptions of the several storms, are worthy of attention, especially those from Mr. Wm. C. Appleton on July 29, from Newburyport on June 14, and those describing the ending of a storm on August 4. But little attention is given to cloud observations. A few simple records of the growth and movement of the thunderstorm clouds would give valuable results, and it is believed by the writer that careful attention to this subject would help greatly in a full discussion of the theory of thunderstorms. Further, each observer, by noting the growth and movements of the thunder clouds, can, with a little practice, make tolerably accurate forecasts for himself of the approach of thunderstorms. To this end the movement of the overflowing cirrus cover, which usually runs an hour or more ahead of the storm, should be carefully noted; for it appears from the study of these storms so far that they seldom occur unless there is a cirrus overflow from the top of the general cumulus cloud mass. In this direction there seems to be an attractive and a useful line of work.

The materials at hand at present are not sufficient for a complete discussion of the general theory of thunderstorms in relation to the thunderstorms of New England, and therefore this portion of the subject is deferred to a later date. It may, however, be stated here, that, as has been seen, the great majority of the thunderstorms of New England occur in the southeastern, southern, or southwestern octants of cyclonic centers central over the Lakes, the Lower St. Lawrence, or the Gulf of St. Lawrence. This clearly shows that their convectional overturning is generally due partly to the imported warmth brought in the warm southerly winds of the cyclonic circulation and not only to the warming due to local insolation. They do occur on hot, anticyclonic days, but less frequently, and the storms under such conditions are usually small affairs, of moderate character, and only move a few miles. They have been well described in the reports several times, the observers noting their beginning as an ordinary cumulus cloud of small size, which gradually grows upwards and soon brings rain, with moderate thunder and lightning. The storm is usually noted as of small extent north and south, and as fading away after an hour or less.

The data from one summer's investigation are of course too few to give any reliable averages. A few general facts may, however, be noted here. The majority of the thunderstorms of New England have their origin outside of this district, and come to it ready-made from the West; they are mostly large disturbances, covering many miles, in several cases two or three hundred miles, and move in a systematic way in an easterly direction. The lines showing the positions of the rain-front at successive hours and half-hours usually run in a NE.-SW. direction, which gives the storm, when charted, the appearance of a southeasterly movement. It is believed, however, that the storms usually move in a more easterly or even northeasterly direction, but sidle along, as it were, their broad rain-front extending from northeast to southwest. This gives them practically a southeasterly movement. The convex rain-front lines, which are a general characteristic of thunderstorms, are clearly brought out in several of the charts.

With regard to the classification of the storms, according to progression and non-progression, adopted in this report, it may be stated. as already mentioned above, that the storms which do not show distinct movement across the country and which cannot be charted on the general plan herein adopted, are generally moderate and local in character, and seldom do damage. It has already been seen that the days on which thunderstorms were reported, but on which no movement can be made out, bring only few and scattered reports. The hours of maximum frequency during the summer were 4–8 p. m.; the average velocity was a little less than 30 miles an hour.

One of the notes most frequently made in the records is on the dividing of the storms before they reached the observer. Indeed, almost every storm during the summer was noted as dividing at one or more stations. With reference to this phenomenon it may be said that it is very likely that the small local storms, which last but a short time, can be, and are often, influenced by the topography of the country, that is, by the mountains and river valleys. It does not seeem possible, however, that the larger storms which ascend thousands of feet into the atmosphere, which may move several hundred miles, and which cross the White and Green mountains and the Berkshire Hills apparently without any change in their movement, can be influenced by small isolated hills or river valleys. The account given by the observer at Dublin, N. H., confirms this point, at least as far as that station is concerned. He says that Mount Monadnock causes the smaller storms to divide every time they come to it from the west, and that the two parts go northeast and southeast, respectively, leaving, as he reports, Dublin in the center of two rainy belts, without a drop of rain there. This dividing, he says, happens only when the storms are small, and when their northern and southern limits can be seen. In the case of larger and more severe storms, whose limits can not be seen, the mountain has no effect.

Many cases of the apparent effect of topography can undoubtedly be explained by the fact that when an observer sees a thunderstorm coming from the west he expects it will pass over him, no matter what the direction of movement of the storm. If the storm does not move over the observer, but in its regular course moves northeast or southeast of him, he is very apt to attribute this to the influence of neighboring hills or valleys. Another very common belief is that certain districts are more exposed to damage by thunderstorms, including lightning and hail, than others near by. This point is an interesting one for further investigation, but at present no definite statement can be made with regard to it.

In presenting this report the writer feels that it by no means contains all the results that can be obtained from the data collected during the summer of 1892, but it does bring out some of the main facts concerning the thunderstorms of New England, and as a preliminary contribution to further work when more data are at hand it cannot fail to be of value.

ROBERT DEC. WARD.

HARVARD UNIVERSITY.
CAMBRIDGE, MASS., *March* 1, 1893.

REPORT ON THUNDERSTORMS IN OHIO DURING THE SUMMER OF 1892, BY MR. CHARLES M. STRONG, OBSERVER, WEATHER BUREAU, COLUMBUS, OHIO.

COLUMBUS, OHIO, *October* 22, 1892.

SIR: I have the honor to submit herewith a report on thunderstorms in Ohio during the months of June, July, and August, 1892.

During June, July, and August thunderstorms occurred on forty-eight days in the various portions of the State. For the northern section of the State forecasts for this class of storms were issued from Cleveland on twenty-two days, and all were verified by the occurrence of storms in some portion of the section; thunderstorms were reported on twenty-four days for which no forecasts were issued. For the southern section of the State forecasts were issued from Cincinnati on ten days, and were all verified; thunderstorms occurred on thirty-two days for which no forecasts were issued. For the central section of the State, covering a radius of 50 miles around Columbus, warnings were issued on thirty-three days, of which thirty-one were verified and two not verified.

The above warnings were issued and based on the morning daily weather charts of the three stations. In addition to these, warnings were issued from Columbus based on telegrams received from Cincinnati, Louisville, and Indianapolis on five days, and of these two were verified and three not verified. Within the Columbus district seven thunderstorms occurred for which no warnings were issued. The percentage at these three forecasting stations, in the forecasts issued from the daily weather map, is very good, considering the limited knowledge as to the circumstances under which this class of storms develop.

No date for which the probability of the occurrence of these storms was forecasted occurred without the happening of the condition in some portion of the section. The great drawback to this excellent record is the simple fact that thunderstorms occurred on so many days for which no forecasts were issued.

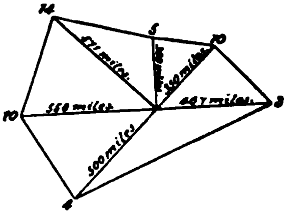
I have the honor to submit the following conclusions which I have drawn from the charts made for this season, which I submit only as inferences, which may or may not be supported by the work of future seasons.

1st. *Movement of thunderstorms across the State.*—Thunderstorms appearing over the northwest portion of the State during the season have either moved to the northeast over the counties adjoining the lake or have taken a southerly trend to the southward of the northern watershed over the Scioto and Muskingum valleys and passed southeasterly into West Virginia. Those appearing over the central-western border have moved east to the central portion of the State, and thence northeast to the Lakes or southeast over the Muskingum Valley to West Virginia. Those appearing over the southwest border have moved east along the Ohio Valley or dissipated. Those starting over the south-central portion of the State have moved northeast along the Ohio or southeast into West Virginia.

Of the various storms 46 per cent have moved to the southeast; 25 per cent to the northeast; 29 per cent to the east. The general trend of all well-developed storms appears to be to the southeast, over the central portion of the State, and is due, I should think, to the general contour of the southern portion of the State, the heated atmosphere of the numerous valleys therein, and the easterly movement of the surface air. The high elevation of the central-eastern and northeastern portions of the State exerts a more or less perceptible influence towards warding off the local storms to the southeast.

During the month of June the average velocity of the storms moving to the southeast was 25 miles; northeast, 26 miles; and east, one storm, 42 miles. During July, southeast, 32 miles; northeast, 17 miles, and east, 25 miles. During August, southeast, 32 miles; northeast, 36 miles. The average movement for all storms during June was 28 miles; July, 22 miles; August, 29 miles; and for the season, 26 miles. The greatest development and spread of any single storm was on August 9, when the electrical display was noted at two points 40 miles apart in twenty minutes, the least rapid occurred on June 27, when a rate of 10 miles was recorded.

2d. *Positions of low areas when thunderstorms occurred.*—During the month of June the centers of general storm areas were distant from the State in an average number of miles as follows: NW., eight days, 500 miles; W., four days, 500 miles; SW., one day, 400 miles; NE., six days, 400 miles; N., one day, 100 miles, and E., one day, 500 miles. During July, as follows: NW., three days, 700 miles; W., five days, 600 miles; NE., two days, 450 miles, and N., two days, 450 miles. During August, as follows: NW., three days, 430 miles; W., one day, 300 miles; SW., three days, 530 miles; NE., two days, 170 miles, and N., one day, 400 miles.



The above diagram is intended to illustrate the position of the low areas relative to the State of Ohio on the days on which thunderstorms occurred within the State. The outside figures being the number of days on which thunderstorms occurred in the different relative positions of the low area, and the inside figures the average number of miles the low areas were distant when they occurred. From the diagram it can be readily seen that the thunderstorms occurred the greatest number of times when the low area was in the northwest, and it will be noted that they could be anticipated when the main storm was 900 miles distant, with a recurrence from day to day, as long as the main low area maintained a position to the west or northwest. Over 50 per cent of these storms occurred with the low areas in this position as regards Ohio. The next most frequent direction was when the main storm had attained a northeasterly direction as regards the State, and in the main appears to have been caused by the changes in temperature that accompany the passage of a large storm, the thunderstorms being mainly light and local in character and moving toward the southeast in advance of the general westerly or northwesterly winds. As shown by the diagrams, no thunderstorms occurred with the main low area to the south and southeast during the season. Whether the rule would hold that they do not originate with the low areas in the southeast quadrant remains for future work to disclose. Thunderstorms of July 11, 24, and 30 are phenomenal in movement, and unexplainable unless caused by a retrogression of thunderstorm energy.

3d. *Predictions of thunderstorms based on telegrams and upon the daily weather map.*—In regard to the successful prediction of thunderstorms, based upon telegrams received from points to the west and southwest, issued to points over the State in advance of the thunderstorms, I do not think it worth the expense involved. It is almost an impossibility to make a direct prediction as to the time and place with the information obtained in this manner. The movements of the different storms vary so greatly as to direction and velocity that a successful prediction is due more to chance than anything else. Predictions issued upon the daily weather map in the form of "probabilities" without any specification as to time or place, except the day and section, are far more applicable, and, with the limited knowledge at hand, successful, than the former class. This is most thoroughly evidenced by the record of the past season. While it might be profitable, if available, to use the telephone in tracing these storms across the State, still the warnings given in advance would be of such short time that no preparation to meet the exigency could be made. With the issuance of the "probabilities" and their diffusion over the State, the person interested, knowing that local storms of this character were anticipated, could so conduct his work as to protect himself from any serious loss.

I do not think the time has come for more definite forecasts than are at present given. The predictor, knowing the local peculiarities, the average path of development of the thunderstorms under a general set of conditions, and the general conditions, can make with a great deal of certainty his local forecast for his section, and be sure to make a fairly good percentage. The success will, however, depend in a great degree upon the ability of the forecaster, individually, to grasp all the points bearing on his section, and to state them in as few words as possible.

Hoping that I have covered the ground as desired, and as fully reviewed the season as necessary, I remain,

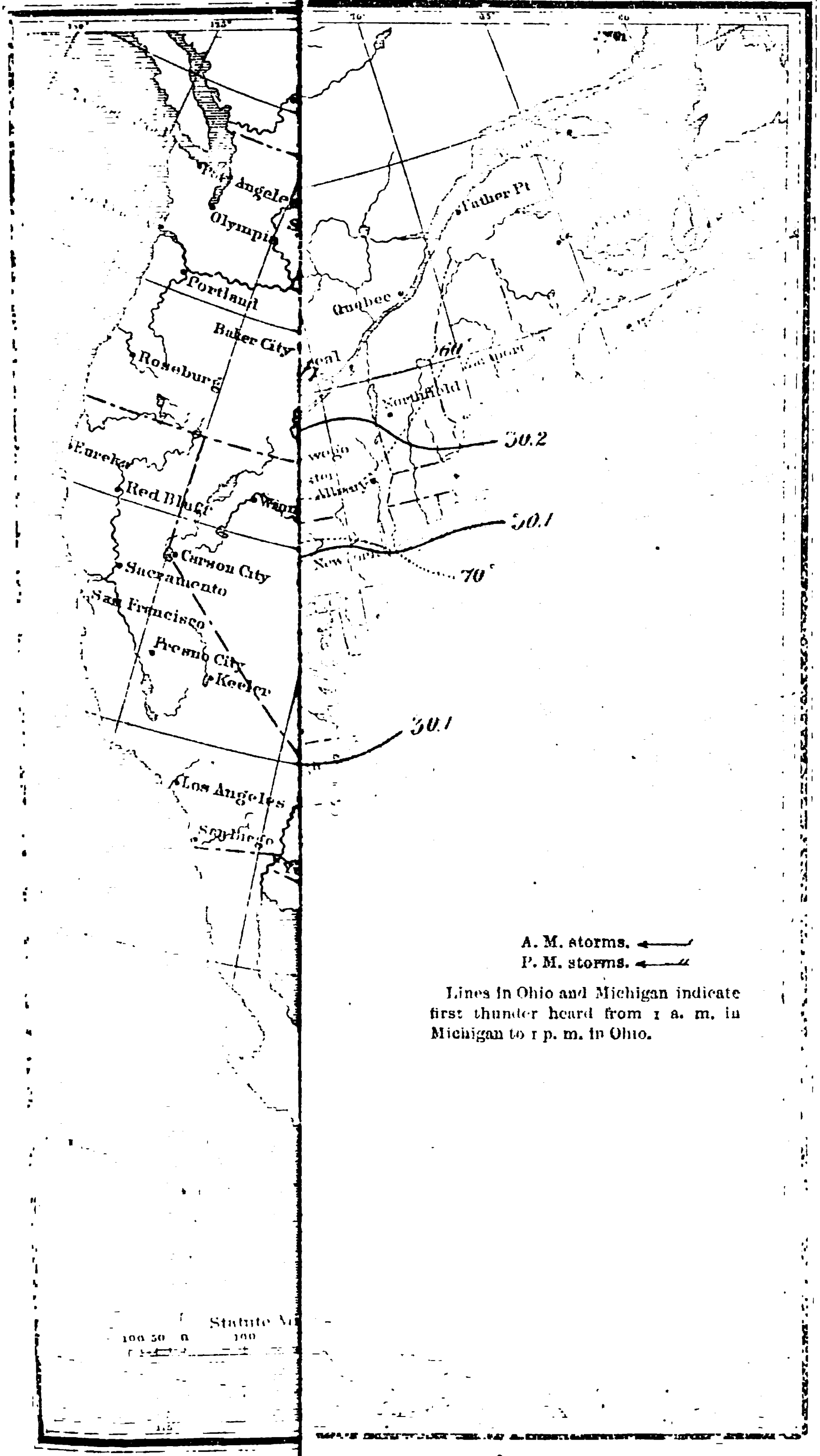
Very respectfully,

CHAS. M. STRONG,
Observer Weather Bureau.

CHIEF OF THE WEATHER BUREAU,
Washington, D. C.

same Date.

Form 106 F.

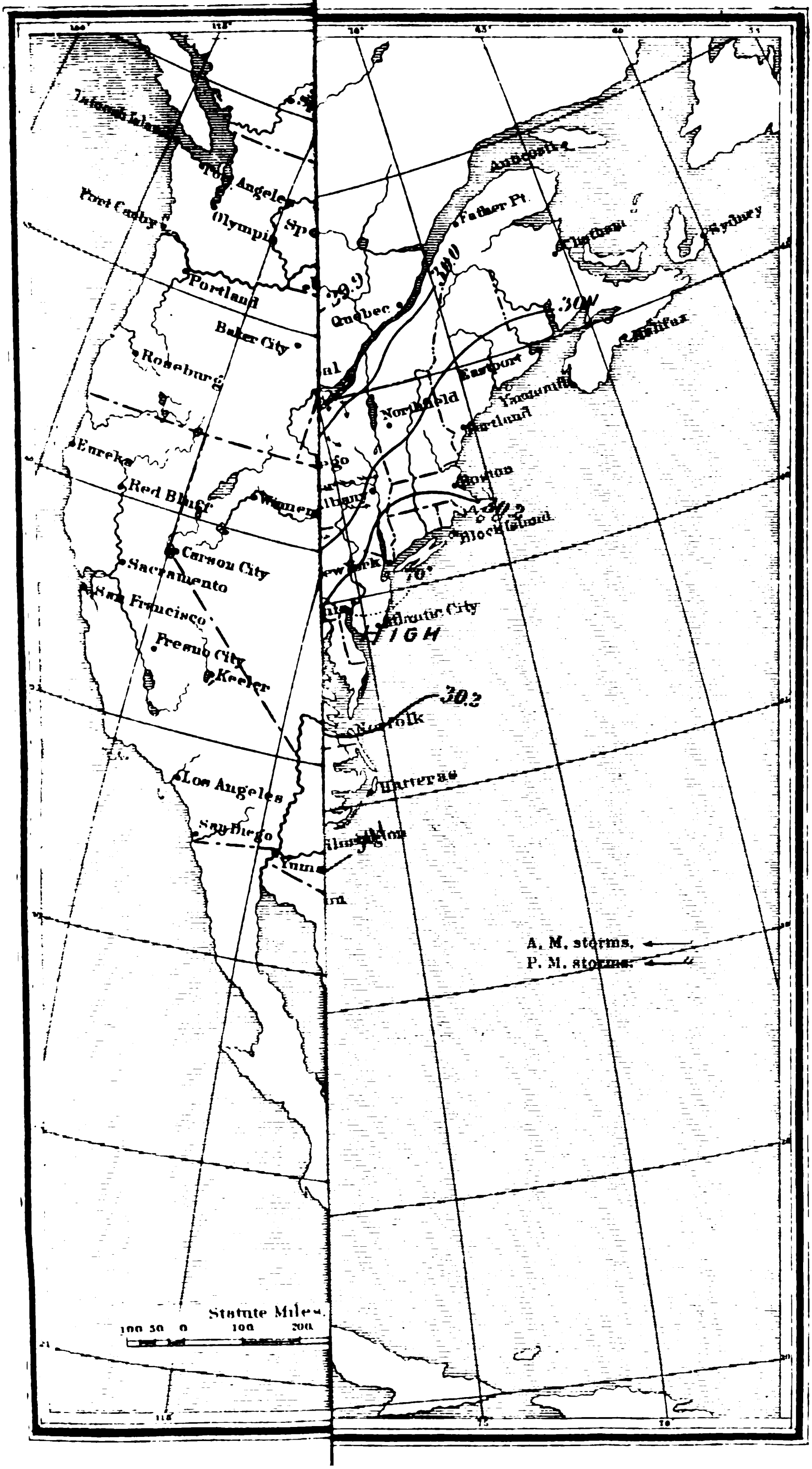


A. M. storms.

P. M. storms.

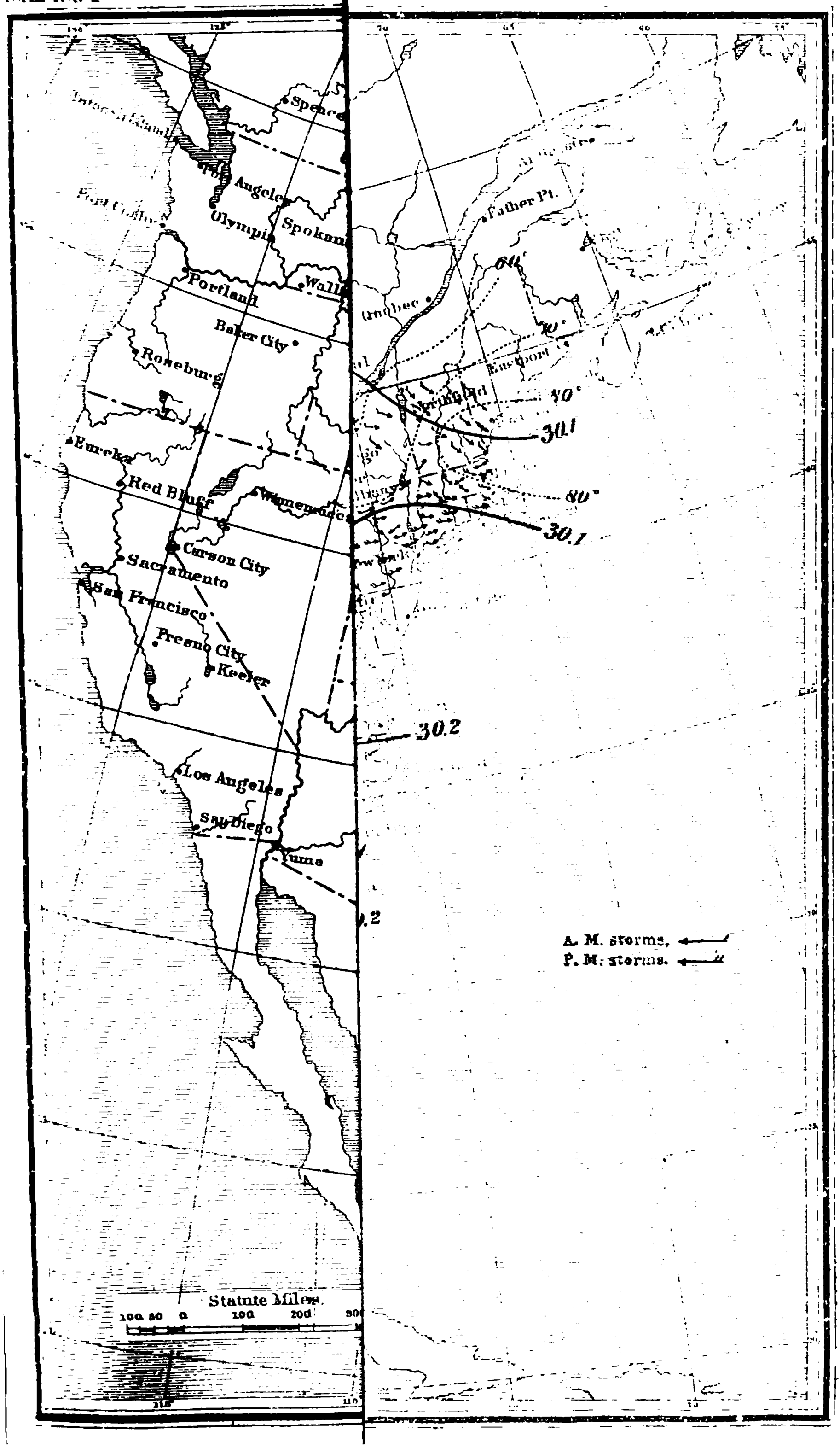
Lines in Ohio and Michigan indicate first thunder heard from 1 a. m. in Michigan to 1 p. m. in Ohio.

f same Date


Portland
Baker City
Roseburg
Eureka
Red Bluff
Winnemucca
Carson City
Sacramento
San Francisco
Fresno City
Keeler
Los Angeles
San Diego
Yuma
Olympia
Port Angeles
Port Canby
Quebec
Northfield
Eastport
Portland
Boston
Block Island
New York
Atlantic City
Norfolk
Hatteras
Father Pt.
Anticosti
Chatham
Sydney
Halifax
Yarmouth
29.9
30.0
30.0
30.2
30.2
HIGH
A. M. storms.
P. M. storms.
Statute Miles.
100 50 0 100 200

of same Date.

Form 106 F



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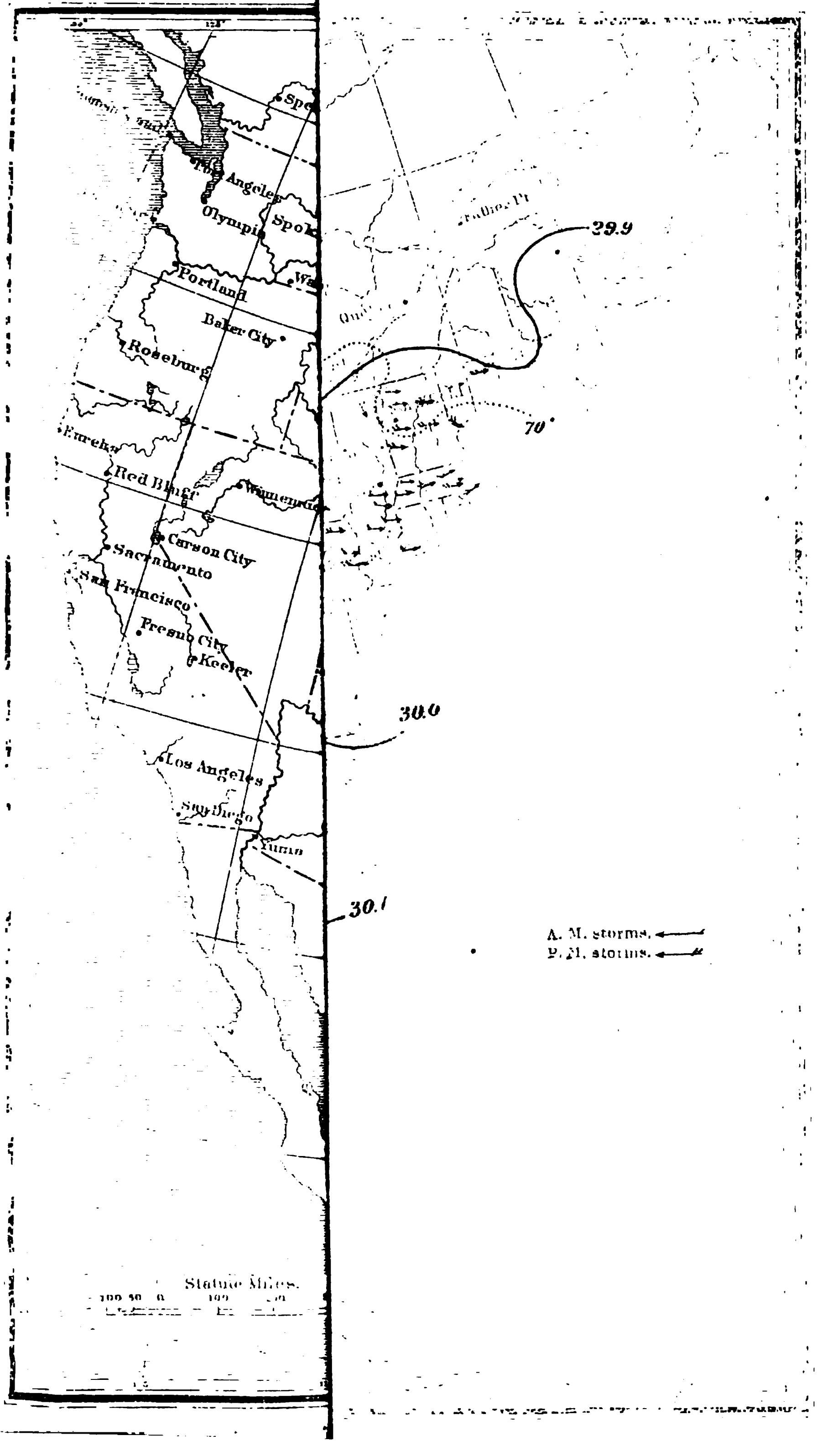

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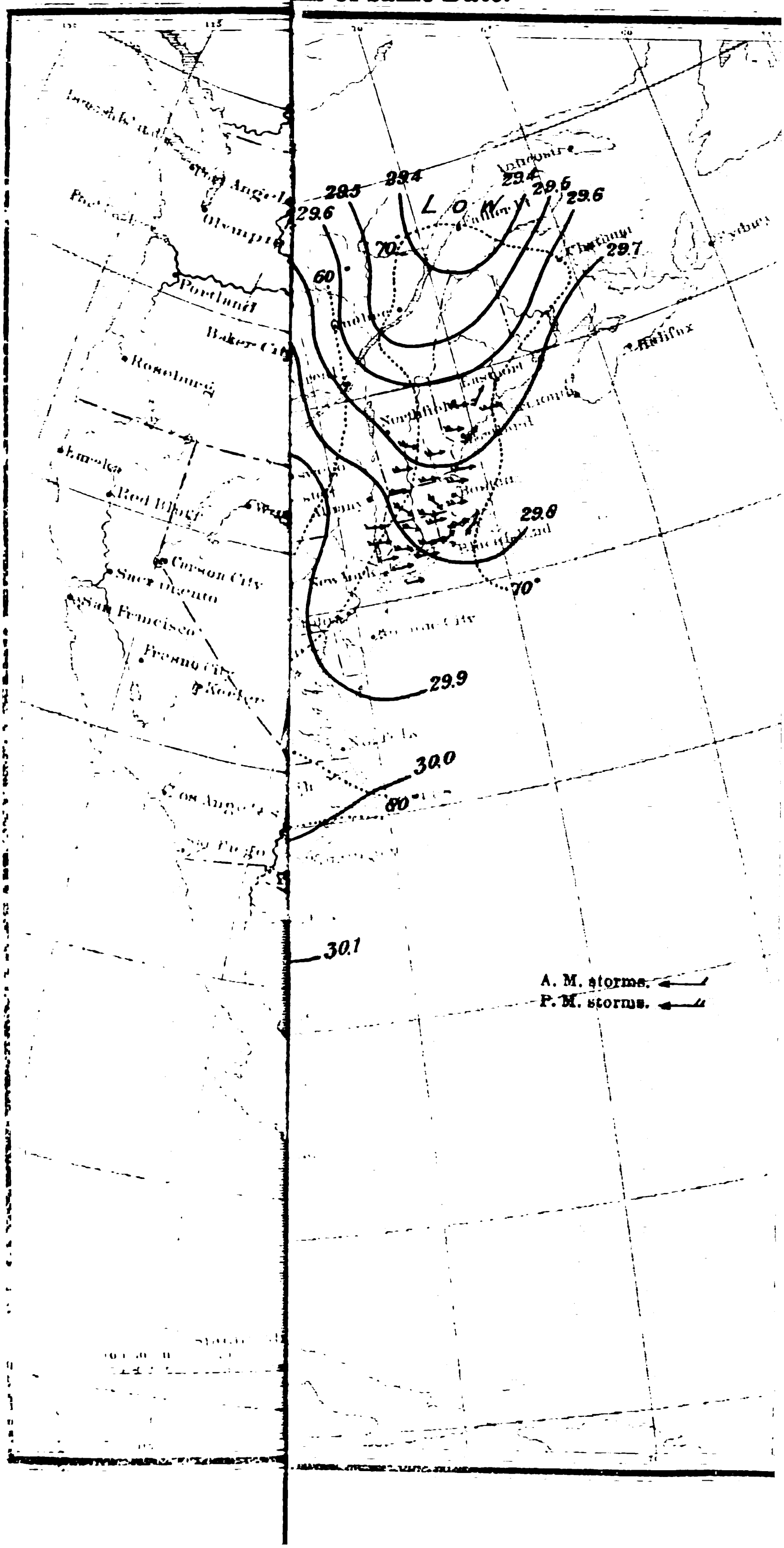

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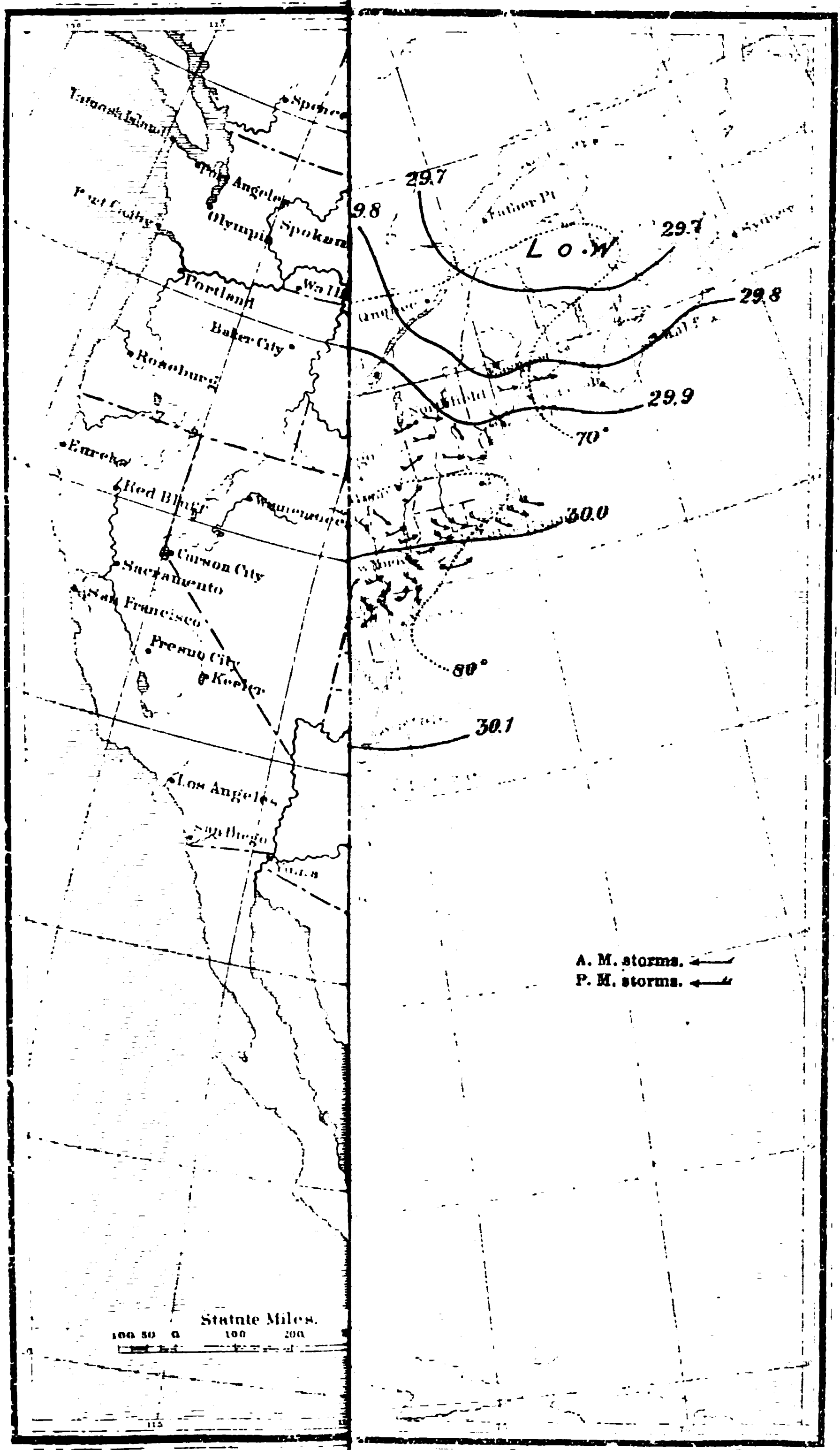

Tatoosh Island
Port Angeles
Olympia
Spokane
Portland
Baker City
Roseburg
Eureka
Red Bluff
Winnemucca
Carson City
Sacramento
San Francisco
Fresno City
Keeler
Los Angeles
San Diego
Yuma
Low
29.7
29.7
9.8
29.8
29.9
30.0
30.1
70°
80°
A. M. storms.
P. M. storms.
Statute Miles.
100 50 0 100 200

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 10.

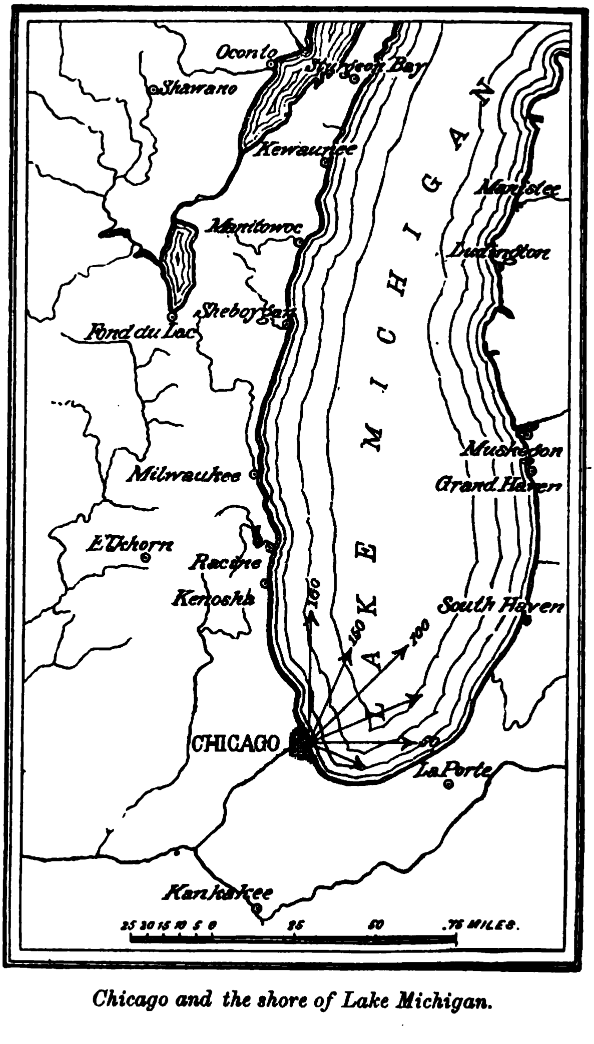
THE CLIMATE OF CHICAGO.

BY

HENRY A. HAZEN,
PROFESSOR OF METEOROLOGY.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
1893.



Chicago and the shore of Lake Michigan.

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1893.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., July 12, 1893.

SIR: I have the honor to transmit herewith a paper entitled "The Climate of Chicago," which has been prepared by Prof. Henry A. Hazen, of this Bureau, and to recommend its publication as Weather Bureau Bulletin No. 10.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. J. STERLING MORTON,
Secretary of Agriculture.

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THE CLIMATE OF CHICAGO.

LOCATION OF CHICAGO.

The city of Chicago is situated on the west shore of Lake Michigan. The courthouse is in latitude 41° 53′ north, longitude 87° 37′ west, from Greenwich. The frontispiece shows the general trend of the shore of the lake. The following measurements indicate the water surface which would be traversed by different winds: north, 150 miles; north-northeast, 300 miles; northeast, 108 miles; east, 50 miles; southeast, 25 miles. The land surface about Chicago is almost level prairie. The elevation of the lake (high water of 1848) is 582 feet above the sea. The highest land in the State, so far as measured and recorded, is at Warren in the extreme northwest, 1,005 feet. The elevations of the following towns will show the general heights within 50 miles of the city: Saint Ann, 660 feet; Kankakee, 626 feet; Geneva, 717 feet; Elgin, 713 feet; and Aurora, 648 feet. It will be seen that the general elevation of the whole land surface is not more than 100 feet above the plane of the city.

METEOROLOGIC OBSERVATIONS.

The earliest meteorologic observations that have been preserved were made at Fort Dearborn, near the lake shore, in July, 1832. This series was continued until December, 1836, when there is a gap up to December, 1856, excepting a few observations at the Mechanics' Institute, in 1844. From January 1, 1858, to October, 1859, no records are on file, but since November, 1859, a continuous series of observations has been maintained down to the present time, with the exception of 14 days in October, 1871, which were lost in the great fire of October 8 and 9. These remarks apply to observations of temperature. For rainfall the records are not so complete.

Previous to November, 1870, when the Army Signal Service began observations, the following persons took observations: S. Meacham, S. Brooks, J. G. Langguth, W. S. Kauffman, C. E. Brinsmade, A. M. Byrne, G. D. Hiscox, and others. There has been no fixed place for these records, some of them have been at the University and others at various places in the city. All records of this description in the immediate city have been badly broken by the fire.

WEATHER SERVICE RECORDS.

On October 15, 1870, the U. S. Army Signal Service station was established at No. 162 E. Washington street, and observations have been maintained continuously since that time, except for 14 days in October, 1871. The following table gives the location of each office, with date of establishment and height of each instrument. The records before October, 1871, are somewhat uncertain, as the complete obliteration of many records and the buildings themselves has prevented a recovery of measurements. It will be noted that there has been a rather steady increase in the heights of all the instruments down to February, 1890, and this will make it quite difficult to obtain absolute comparisons between the records at the different offices, except those of the barometer, clouds, fog, storms, etc.

Table I.—*Position of each Signal Office in Chicago, with elevation of each instrument.*

Established.	Office.	Room.	Barometer above sea.	Thermometer above ground.	Rain gauge above ground.	Anemometer above ground.	Wind vane above ground.
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Oct. 15, 1870...	162 E. Washington st..............	21	651	57	?	?	?
May 1, 1871 ...	164 E. Washington st..............	52	651	57	67?	85?	85?
Oct. 15, 1871...	10 W. Randolph st.	2	633	32	43	72	72
June 11, 1872..	80 S. Market, Central Block........	....	667	74	97	108	113
June 8, 1873...	SE. cor. Madison & La Salle sts....	78	661	70	93	103	108
Jan. 1, 1887....	SW. cor. Clark & Washington sts..	1028	715	146	132	153	155
Feb. 1, 1890...	Auditorium Building..............	....	824	241	238	272	272

Table II.—*Names of the observers in charge of the Chicago station from establishment to present time.*

Name.	From—	To—
James Mackintosh....................................	October 10, 1870 (about).	July 17, 1872.
Theodore Mosher....................................	July 17, 1872............	January 2, 1873.
A. C. Ford..	January 2, 1873..........	May 1, 1876.
C. E. Brinsmade....................................	May 1, 1876..............	November 6, 1877.
S. S. Bassler.......................................	November 6, 1877.........	December 21, 1877.
J. M. Clifford......................................	December 21, 1877........	January 23, 1878.
J. J. Lynch...	January 23, 1878.........	January 9, 1880.
Jas. Mitchell..	January 9, 1880..........	March 8, 1883.
John Laurens.......................................	March 8, 1883............	June 26, 1883.
Wm. Norrington....................................	June 26, 1883............	March 18, 1884.
T. B. Jennings.....................................	March 18, 1884...........	July 25, 1885.
Allen Buell...	July 25, 1885............	December 1, 1887.
H. C. Frankenfield..................................	December 1, 1887........	In charge at present.

INFLUENCE OF THE LAKE.

In studying the climate of Chicago, the greatest interest at once centers upon the lake and the influence of its waters upon the temperature, rainfall, winds, clouds, etc. While it is true that the broader features of the climate are dependent upon atmospheric causes and influences taking their rise to the westward and northwestward of the city, yet these are often markedly changed by the lake and the conditions induced by its temperature and moisture. These influences may be classed under two heads:

1st. The influence of the moisture evaporated from the lake and the general or permanent influence of the presence of the lake upon temperature, etc.

2d. The effect of winds coming from the lake or blowing over the lake.

TEMPERATURE OF THE LAKE.

Water temperatures have been taken at the crib since 1874, and these form a most valuable series. Temperatures were also taken at a depth of 25 feet by the city authorities, but it was soon discovered that there was a most extraordinary uniformity between the surface temperature and that at a depth of 25 feet, the difference seldom being one degree. On inquiry it was learned that the temperatures at 25 feet were made in the well of the waterworks, and could not be used for determining the actual temperature in the lake at that depth. This would be a most interesting fact to determine, that is, the comparative quickness of change in temperature in the lake at the surface and at a depth of 25 feet, and, if possible, 50 or more feet. It would be a simple matter to get this temperature, and it is to be hoped that the authorities will take steps to make the measurements.

The Weather Service observer also took a record at the shore, but this was discontinued in the cold season, while the crib observations are taken through the year. A comparison of a few of the complete months at both places has shown that in the winter, spring, and summer the shore temperature has a tendency to run slightly higher than the crib, but in the fall the crib is frequently the higher. This shows the influence of the land surface with a rising temperature.

Table III gives the monthly temperature of the water at the crib, and of the air at the Weather Service station. It was noticed that sometimes in the winter the mean monthly temperature of the water was below 32°, which is a little doubtful result. These figures have been unchanged, as they can have but a very slight effect upon the final means. Examining the means for the 17 years, we see that, on the average, the water and air have the same temperature in March and September. In January the water is 8.9° higher than the air, and in June it is 9.1° lower than the air. These figures are of great interest, which will be still further brought out in studying the influence of the wind.

TABLE III.—*Water and air temperature, Chicago.*

Month.	1874.			1875.			1876.			1877.			1878.			1879.			1880.			1881.		
	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	32.0	32.0	28.9	32.0	33.9	17.9	35.0	33.3	33.0	33.0	32	22	33	33	31	32	32	21	36	33	40	32	33	20
February	32.0	34.3	31.4	32.0	33.0	14.7	36.2	32.7	31.8	34.6	34	36	32	32	36	32	34	27	35	33	35	32	34	25
March	32.0	35.5	36.5	32.0	32.4	31.8	36.5	33.5	33.9	33.7	33	29	42	38	44	37	35	39	34	35	38	32	35	32
April	40.2	39.7	38.6	38.3	37.4	42.5	45.8	39.2	46.5	44.6	40	45	48	45	52	44	40	47	48	43	48	32?	36	42
May	52.7	50.2	59.3	48.9	47.1	55.5	54.8	48.6	59.0	53.8	48	57	55	53	56	53	51	58	68	52	64	57	50	61
June...............	62.8	63.5	70.5	60.7	55.0	63.1	59.2	54.0	67.5	58.3	56	66	63	60	65	58?	56	65	77	57	70	62	56	63
July	69.7	68.5	74.8	66.4	63.9	68.8	66.5	64.5	73.5	69.6	64	73	71	69	75	72	66	73	68	66	72	72	71	73
August	70.6	71.0	71.8	66.1	65.5	68.4	70.0	66.5	73.5	68.8	68	71	73	72	74	71	68	73	73	68	72	75	74	75
September...............	67.9	70.3	66.4	60.4	60.4	61.0	65.0	63.7	61.1	65.9	66	66	67	64	66	64	63	61	67	65	62	65	64	70
October...............	55.9	58.1	53.0	51.7	50.3	47.5	52.0	50.5	48.8	55.4	58	55	54	54	52	60	56	60	54	50	51	57	55	56
November	42.3	47.8	40.3	39.4	41.1	37.0	44.2	43.5	39.3	42.7	44	40	42	42	43	41	43	42	42	40	31	43	44	40
December	31.9	34.7	33.5	34.8	33.7	36.8	33.0	32.5	20.0	38.0	37	43	33	34	24	33	35	30	33	32	23	37	36	37
Mean	49.2	50.5	50.4	46.9	46.1	45.4	49.9	46.9	49.0	49.9	48.3	50	51.1	49.7	51	49.8	48.2	50	52.9	47.8	51	49.6	49.0	49

Month.	1882.			1883.			1884.			1885.			1886.			1887.		1888.		1889.		1890.		Mean.	
	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Wharf.	Crib.	Air.	Crib.	Air.	Crib.	Air.	Crib.	Air.	Crib.	Air.	Crib.	Air.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	33	32	28	32	30	16	32	36	19	32	36	18	32	32	21	32	17	32	15	32	29	34	31	32.9	24.0
February	37	33	38	32	30	23	32	35	28	32	36	17	32	33	28	31	27	32	23	32	20	33	32	33.1	27.8
March.........	38	35	38	32	32	31	32	34	34	32	37	30	32	33	36	32	32	32	30	36	38	33	30	34.3	34.3
April	46	42	46	32	41	46	43	40	44	44	43	45	45	40	49	38	47	40	45	43	47	41	46	40.6	45.7
May	......	46	52	......	52	52	53	49	57	54	49	53	56	51	57	51	59	47	53	52	57	49	53	49.1	56.6
June	......	54	64	59	57	64	61	56	65	60	56	65	64	57	66	59	67	56	67	55	62	56	70	56.8	65.9
July	66	62	69	62	62	71	68	64	69	64	61	73	70	66	71	65	76	65	73	66	70	68	72	65.3	72.2
August.........	72	69	71	68	67	68	67	62	69	69	65	68	71	68	72	69	70	66	69	64	71	66	68	67.6	70.9
September	69	66	65	63	65	61	64	60	69	65	62	64	66	63	66	64	62	64	60	57	63	62	60	63.6	63.7
October	60	60	56	54	56	52	56	56	56	54	55	51	56	55	57	53	47	50	49	51	49	56	51	54.4	52.4
November	46	46	42	42	45	42	43	45	40	......	44	42	40	44	38	40	38	45	42	43	39	43	42	43.6	39.9
December	33	32	26	33	39	30	33	37	28	......	33	31	32	32	25	33	28	35	32	36	41	32	31	34.6	30.3
Mean.........	......	48.1	50	......	48.0	46	48.7	47.8	48	......	48.1	46	49.7	47.8	49	47.3	48	47.0	47	47.4	49	47.8	49	48.0	48.6

The minimum of both air and water comes in January. The maximum of the air is in July, 72.2°, but that of the water is in August, 67.6°. An examination of the annual means seems to show a gradual lowering of the temperature in the later years, but the same is noted in the air temperature. It would be of some interest to discuss the question whether the mean temperature of the lake from year to year would not be a better criterion than the air temperature for determining a secular variation. For this purpose, careful observations at a depth of 50 feet would be better than those at the surface. The annual amplitude of the lake temperature since 1877 has been from 49.7° to 47.0°, and of air temperature it has been from 51° to 46°, or nearly double that of the lake surface.

LAKE TEMPERATURES AT GRAND HAVEN AND MILWAUKEE.

For purposes of comparison, similar temperatures of water and air at Grand Haven and Milwaukee are given in Table IV.

TABLE IV.—*Water and air temperature at Grand Haven, Mich.*

Month.	1876.		1877.		1878.		1879.		1880.		1881.		1882.		1883.		1884.		1885.		*1886.		Mean.	
	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	34	32	32	24	34	31	32	25	32	37	32	20	32	28	32	20	32	21	32	21	32	20	32.2	25.4
February	32	29	33	33	33	34	32	23	33	32	32	24	31	36	32	24	32	25	32	15	32	23	32.2	27.1
March	34	30	33	28	42	43	36	35	39	34	33	31	35	35	32	27	36	32	32	23	33	30	35.0	31.6
April	47	45	50	46	52	52	45	44	49	44	50	40	43	44	48	44	47	44	46	43	52	47	48.1	44.8
May	60	55	61	58	54	53	62	58	66	61	68	62	52	52	58	51	61	55	59	53	63	52	60.4	55.5
June	72	66	71	64	67	63	71	64	72	67	71	62	65	63	68	62	74	68	71	60	72	61	70.4	63.6
July	78	71	76	69	77	73	80	72	77	70	77	71	70	66	73	67	75	67	76	67	73	66	75.6	69.0
August	77	70	74	69	76	70	74	68	76	68	76	71	71	69	71	65	74	66	71	61	74	67	74.0	67.6
September	65	58	69	64	69	63	61	58	65	60	71	67	65	62	65	57	70	65	65	60	67	62	66.5	61.5
October	48	47	57	53	55	51	62	58	52	49	58	52	55	55	53	48	58	54	53	46	56	52	55.2	51.4
November	43	39	41	39	41	41	43	39	39	32	41	40	39	40	41	41	41	38	41	39	39	35	40.8	38.5
December	33	22	38	42	34	28	33	29	33	25	35	37	30	28	33	31	35	28	34	28	33	22	33.7	29.1
Mean	52	47	53	49.3	53	50.2	53	47.8	53	48.2	54	48.1	49.0	48.2	50.5	44.7	52.9	47	51	43	52.2	44.8	52.0	47.1

Water and air temperature at Milwaukee, Wis.

Month.	1874.		1875.		1876.		1877.		1878.		1879.		1880.		1881.		1882.		1883.		1884.		1885.		Mean.	
	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	32	23	33	10	33	26	32	15	34	26	32	22	33	35	32	16	32	25	32	13	32	14	32	10	32.4	19.6
February	32	26	32	8	32	25	33	32	34	32	32	23	34	28	32	23	32	36	32	20	32	22	32	10	32.4	22.4
March	35	31	35	26	32	28	33	23	39	40	35	36	35	32	35	30	36	35	32	29	32	30	35	24	34.5	30.3
April	42*	36	39	38	41	42	41	41	48	50	42	44	44*	44	42	40	42	43	42	43	41	41	42	40	43.1	41.8
May	51	56	50	52	50*	52	53	53	50	53	48*	54	51	61	53	58	48	49	46	50	49	54	47	50	49.7	53.5
June	59	66	57	60	55	63	63	61	58	62	53	62	53	67	55	60	54	61	55	62	56	60	55	60	56.1	62.0
July	63	71	62	66	61	70	60	69	70	73	62	72	58	69	62	71	58	66	59	68	61	66	58	68	61.2	69.1
August	68	68	61	65	67	70	67	69	72	71	68	69	70	69	70	71	68	68	64	66	60	66	62	63	66.4	67.9
September	63	65	58	57	62	58	64	64	62	63	61	58	63	60	59	64	67	63	60	57	66	64	60	60	61.2	61.1
October	50	50	50	44	50	44	52	50	44	49	51	55	48	48	52	52	56	56	52	49	52	53	54	46	50.9	49.7
November	40	35	40	31	42	35	45	35	38	41	40	36	38	27	42	37	43	40	40	38	42	35	44	38	41.2	35.7
December	32	25	33	32	33	14	39	37	32	22	33	23	33	19	36	35	33	24	32	26	33	23	33	28	33.5	25.7
Mean	47.3	46	45.8	41	46.5	44	48.5	46	48.4	48	46.4	46	46.7	47	47.5	46.4	47.5	47	45.5	43	45.5	44	46.2	41	46.9	44.9

*Interpolated.

The result at Grand Haven is remarkable, for the water temperature appears to be *higher* than that of the air during every month of the year. It seems difficult to account satisfactorily for this anomalous result. It is possible that there is some local effect that produces it. It may be that the water was quite shallow or somewhat embayed so that the sun's heat produced a cumulative effect and the freer waters of the lake did not reach the point where the temperature was taken. I have thought that possibly the surface water was driven on shore by the prevailing westerly winds, and the temperature in this case would be somewhat raised, especially in the summer. It has also been suggested that the current in the lake is from south to north on the east side; this would carry up warm water from the south.

At Milwaukee the correspondence between the water and air occurs in the early part of May instead of March, as at Chicago; in the fall the agreement is in September at both stations.

INFLUENCE OF THE LAKE ON THE AIR TEMPERATURE.

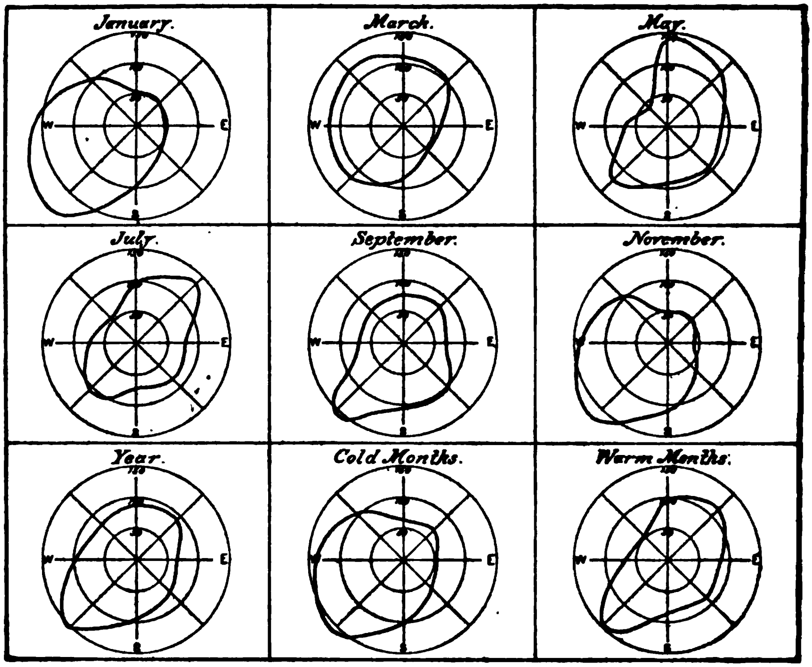
In studying the relation of the lake temperature to that of the air, we may arrange all the temperatures recorded during the prevalence of each wind and then ascertain whether the winds from the lake have a modifying influence, or we way compare these temperatures at Chicago directly with those at any other station not affected by the lake.

PREVAILING WINDS.

Table V gives the number of times the wind was observed blowing from each direction during 18 years. Most of this table is made up from observations three times each day. Fig. 1 presents a graphical arrangement of this table, or the wind rose for every other month, the year, the cold, and warm months. We see that for the year there is a maximum of winds from the southwest, and a secondary maximum from the northeast. During the cold months there is a marked preponderance of land winds while in the warm months there is a slight preponderance of lake winds.

TABLE V.—*Wind direction for eighteen years.*

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
January	99	98	101	112	208	390	334	207	30
February	97	161	105	148	217	278	253	164	19
March	216	201	130	120	175	241	229	244	25
April	271	239	179	156	144	234	145	129	32
May	272	250	181	192	192	252	132	79	31
June	229	212	173	160	167	297	149	103	40
July	190	272	164	166	142	315	149	115	37
August	179	301	190	189	177	260	103	104	47
September	147	164	139	206	212	314	141	143	34
October	142	152	123	155	263	317	170	197	31
November	99	100	84	135	224	347	288	207	16
December	93	78	73	144	227	389	298	228	20
Year	169	186	137	157	196	303	199	160	..
Cold months	126	135	102	131	207	325	278	211	..
Medium months	196	185	142	160	206	288	184	153	..
Warm months	186	237	167	180	175	297	136	116	..



January. *March.* *May.*

July. *September.* *November.*

Year. *Cold Months.* *Warm Months.*

FIG. 1.—*Wind rose for six months, the year, cold and warm months.*

At first sight it might appear that this difference in the prevailing winds would have a disturbing effect upon the determination of their effect upon the various meteorologic elements—temperature, rainfall, etc.,—and this would be the case if we simply summed up the temperature, rainfall, etc., from each wind, as some have done, but this source of error entirely disappears if we determine the relative values of those elements with each wind. For example, suppose we have 300 southwest winds and rain occurring during 60 of them, and 100 east winds with rains occurring during 50 of them, we could not say that rain was more frequent with a southwest than with an east wind, only 20 per cent. of the southwest winds have rain, while 2½ times as many east winds, or 50 per cent., have rain. The only source of error that this difference in the number of winds will introduce will be in the scarcity of observations of temperature, etc., with some of the directions, but this may be eliminated by taking a larger number of months.

Table VI gives the mean temperature by months for each wind direction, from 1875–1877, inclusive, and also the mean for the year, the cold, medium, and warm months. Fig. 2 is a graphical presentation of this table (every other month is omitted). In the colder months we see a most marked influence from the lake, an east wind giving a temperature almost 13° higher than a northwest wind. In the medium temperature months there is little or no influence, as was to be expected, since this is the transition period when the air and water temperatures are nearly the same. At first it appears a little singular that the lake wind does not show a greater cooling of the air during the warm months, in fact, the effect appears almost inappreciable. We must remember that in summer the wind velocity is largely diminished, that is, about 30 per cent. less than in winter, but the more potent influence would seem to be the effect of the earth's heat upon the wind before it reaches the thermometer.

TABLE VI.—*Temperature and wind from* 1875 *to* 1877.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
	°	°	°	°	°	°	°	°
January	25.5	29.0	30.0	30.5	31.0	26.6	15.7	16.1
February	31.4	30.5	34.0	33.0	35.2	24.1	22.1	19.9
March	28.6	25.6	34.3	42.9	44.7	29.2	30.2	23.1
April	41.8	43.3	44.1	48.2	55.9	45.8	46.6	42.4
May	47.3	47.1	54.0	59.2	66.9	65.1	62.9	55.0
June	58.3	59.5	63.6	66.5	71.6	69.3	68.0	66.1
July	66.1	69.2	69.6	72.0	78.3	78.4	74.2	70.8
August	66.8	67.8	71.3	71.4	75.2	73.2	71.7	69.8
September	59.0	63.9	63.3	66.6	66.9	65.3	57.0	53.5
October	47.6	54.3	51.5	53.0	45.1	52.3	46.3	44.3
November	40.8	41.5	43.7	41.8	42.5	40.3	32.6	32.3
December	37.2	36.6	37.7	38.3	38.2	35.1	25.1	26.2
Year	45.9	47.4	49.8	51.9	55.1	50.4	46.0	43.3
Cold months	30.7	30.4	34.0	36.4	37.3	28.8	23.3	21.3
Medium months	44.4	46.6	48.3	50.6	55.1	50.9	47.1	43.5
Hot months	62.6	65.1	67.0	69.1	73.0	72.1	67.7	65.1

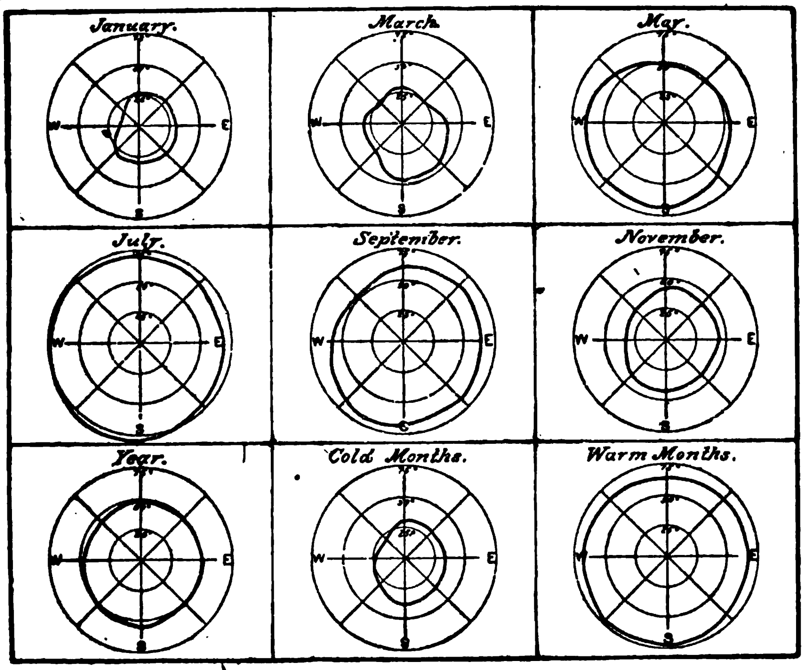


FIG. 2.—*Temperature and wind rose*, 1875–1877.

In addition to this, the problem is much complicated by the cloudiness, the land and sea breezes, etc. We shall see that there is a decided tendency to a lake wind during the afternoon in summer while there is a land wind during the night. In the summer also only about 40 per cent. of the sky is clouded, and the clearest skies are during the night, the result is that a land wind is cooled off a great deal by the strong radiation to the clear sky and this tends to equalize the temperature between lake and land winds. It is not so much that the lake has no effect during the hot season as that the land wind is cooled just at the time when its effect is greatest upon the temperature. We shall see a little later that both these causes tend to keep the summer temperature down, and the diurnal range is about the least of any station in this country east of the Rocky Mountains. During the highest temperatures experienced there is not the least doubt that a shift of wind to the lake cools the air most markedly.

This question is of so great importance that it has been deemed wise to make a second computation during the period 1884–1886. Table VII exhibits these results. Here again we have the same general results that we had before. A marked effect in the cold months but hardly any in the medium and warm months.

TABLE VII.—*Temperature and wind from* 1884 *to* 1886.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
	°	°	°	°	°	°	°	°
January	26.2	27.0	27.9	34.2	27.2	19.0	11.3	18.3
February	28.7	27.2	30.3	36.0	30.6	21.3	16.7	22.3
March	30.5	26.6	39.3	45.0	42.9	35.2	31.5	30.1
April	40.5	42.0	47.6	55.9	61.2	52.5	42.7	38.7
May	48.9	53.7	55.7	60.6	63.8	60.6	53.3	51.2
June	57.7	61.7	64.5	68.1	74.6	73.3	74.0	60.2
July	65.6	68.8	70.7	75.3	75.5	76.7	73.6	69.7
August	65.2	68.7	67.1	72.0	75.4	73.7	69.5	65.5
September	60.3	68.8	66.1	64.9	72.6	69.1	64.3	55.5
October	52.0	53.0	58.7	59.3	58.6	58.5	48.7	49.5
November	39.9	38.1	42.9	44.8	46.4	41.1	34.6	33.1
December	35.2	33.6	30.3	34.6	38.2	26.2	22.1	18.3
Year	45.9	47.4	50.1	54.2	55.6	50.6	45.2	42.7
Cold months	30.1	28.6	31.9	37.4	34.7	25.4	20.4	22.2
Medium months	48.2	50.5	53.8	56.2	59.7	55.3	47.6	44.2
Warm months	59.4	63.2	64.5	69.0	72.3	71.3	67.6	61.7

COMPARISON BETWEEN CHICAGO AND INDIANAPOLIS.

The second method of determining the lake influence would be to compare with some station off from the lake; for this purpose Indianapolis has been chosen, as, on the whole, the best at which we have regular observations. The years 1882–1886 were taken and the months January, May, and July as typical months. Here the lake influence comes out very plainly. In Fig. 3 we see that in January the full black curve for Chicago goes beyond the dotted curve for Indianapolis for lake winds while it is inside for land winds. In May and July, on the other hand, it is wholly within the dotted curve. It should be noted that a part of this effect is probably due to the more southerly latitude of Indianapolis. Also it appears that May is hardly a medium month in a comparison between air and water temperatures, for the latter is 7.5° below the air in May, so that a strict comparison between May and medium months can not be instituted. In fact, on turning to Fig. 2, we see that the May wind rose shows a marked influence of the lake wind in cooling the air, and this serves to corroborate the present result in Fig. 3 for May.

TABLE VIII.—*Temperature and wind from* 1882 *to* 1886.

CHICAGO.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
	°	°	°	°	°	°	°	°
January	25.8	25.9	27.0	30.6	28.4	20.5	14.2	16.7
May	47.8	49.8	53.1	58.5	63.4	60.5	53.4	50.1
July	64.7	67.6	70.	72.7	74.7	75.8	71.8	68.7

INDIANAPOLIS.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
January	21.5	25.0	25.0	31.7	30.1	26.5	16.5	21.4
May	55.1	58.6	59.6	62.9	67.7	65.9	59.1	56.9
July	70.6	71.4	75.1	74.9	76.5	77.2	75.4	72.3

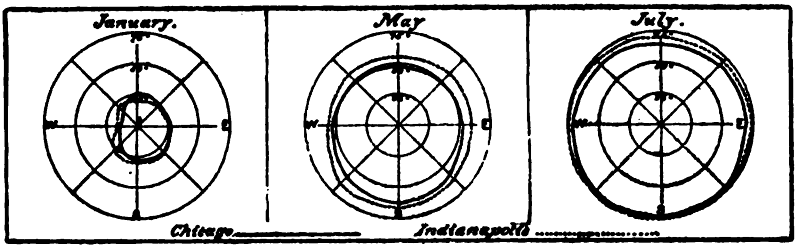


FIG. 3.—*Temperature and wind rose, Chicago and Indianapolis,* 1882–1886.

In order to fully check and also to extend these comparisons, I have made a similar determination for another office in Chicago, and

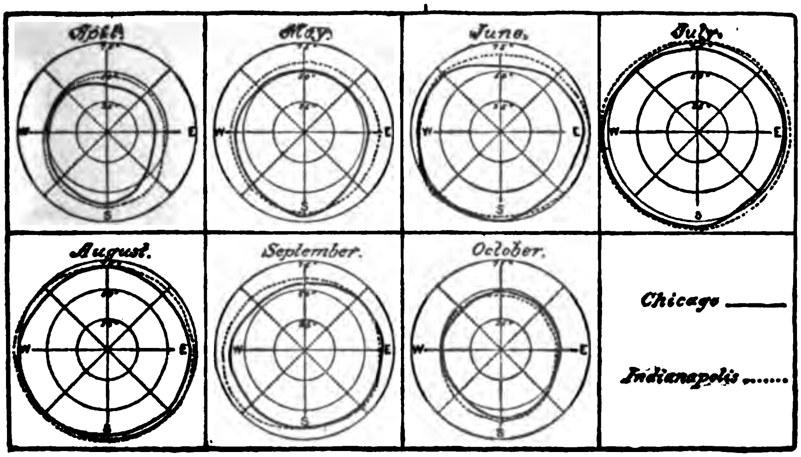


FIG. 4.—*Temperature and wind rose, Chicago and Indianapolis,* 1887–1889.

the period 1887–1889. Table IX shows these results, and the corresponding wind roses will be found in Fig. 4. We see the same effects for May and July as before, and in October the lake influence begins to make itself felt in slightly warming the air.

TABLE IX.—*Temperature and wind from* 1887 *to* 1889.

CHICAGO.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
	°	°	°	°	°	°	°	°
April	38.4	40.1	41.2	47.6	60.5	55.3	48.0	47.2
May	50.0	52.1	54.2	57.2	70.0	60.7	56.8	51.3
June	54.3	61.4	69.3	67.2	75.2	72.8	68.8	67.4
July	69.6	69.7	73.9	71.9	79.1	80.0	79.7	75.0
August	69.1	66.1	69.3	71.4	72.4	75.3	73.2	66.7
September	56.5	61.1	64.5	65.7	64.7	63.3	61.7	53.8
October	48.1	47.7	50.1	52.8	57.4	49.6	48.8	45.6
INDIANAPOLIS.								
April	46	47	47	58	61	60	52	48
May	59	68	64	65	69	66	61	57
June	65	68	75	74	72	75	70	69
July	76	77	79	80	82	82	81	78
August	69	71	73	76	76	78	78	73
September	60	64	63	68	65	71	69	61
October	44	46	47	54	59	56	50	48

GENERAL INFLUENCE OF THE LAKE UPON PRECIPITATION.

The question of a general or more or less permanent effect of the lake on rainfall is not now considered, this would demand a special investigation at a large number of stations about Chicago. It would appear, however, that the Chicago snow and rain fall exceeds in winter that of nearly every Weather Station anywhere near it. In the hot months stations in the Mississippi Valley show a slightly greater rainfall. The Chicago precipitation exceeds that of Milwaukee during nearly every month. It should be borne in mind that this question of the permanent influence of the lake is very much complicated by the effect of the winds as they blow off the lake. This question can be settled quite readily in the same way it was done for temperature.

INFLUENCE OF LAKE WINDS ON PRECIPITATION.

I have determined the proportional tendency of rain with each wind for each month in the year, as given in Table X. Fig. 5 exhibits every other month of this table in graphic form. It is easy to see what a marked influence the lake winds have upon winter precipitation. In the medium and warm months, however, this influence almost disappears, that is, so far as the winds are concerned, there is nearly the same tendency of rain with land winds as with those from the lake. It is certain that the lake winds will have more moisture in them than those from the land. The cause of the less precipitation in the warm months is not far to seek. At the time of the lake breeze, which is relatively cool, the air above the land surface is slightly warmer and the tendency is to diminish the relative humidity of the lake wind, so that, even if the lake breeze were saturated, that condition would be very quickly changed to one of more or less dryness, and, from the very coolness of the air, there would be less chance for rainfall. This is a very important principle to be borne in mind in forecasting precipitation with a lake wind. If this wind is warm and blows upon land which has a lower temperature, there will be a tendency to precipitation; but if it is relatively cool, the heat of the land will tend to dissipate the moisture. This principle will serve to explain the rather singular diminution in the amount of clouds at Chicago during the warm months.

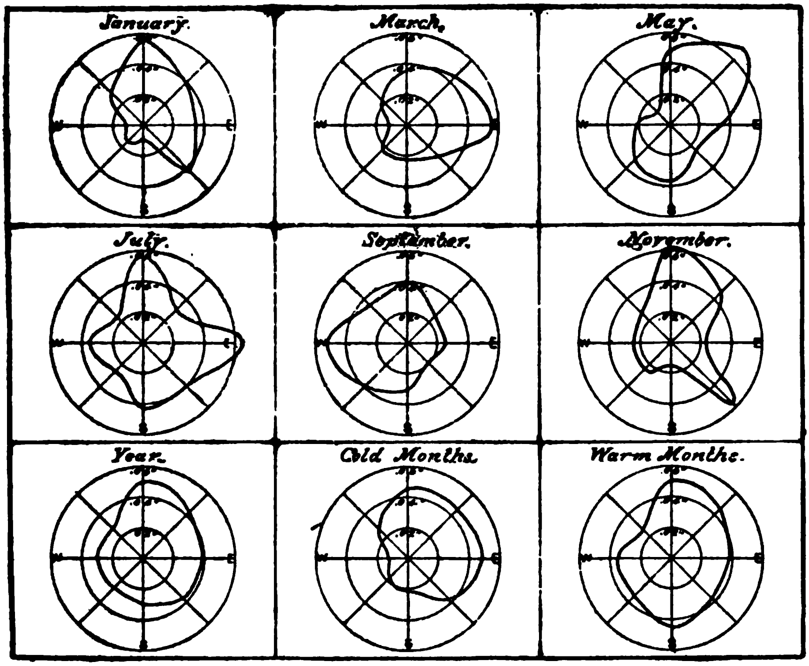


FIG. 5.—*Relative tendency of rain with each wind.*

TABLE X.—*Relative tendency of rain with each wind, Chicago.*

Months.	N.	NE.	E.	SE.	S.	SW.	W.	NW.
Cold.								
January	.056	.039	.034	.038	.008	.014	.010	.035
February	.049	.044	.047	.023	.026	.017	.020	.034
March	.037	.045	.056	.030	.022	.022	.011	.022
October	.089	.045	.033	.040	.024	.026	.051	.042
November	.062	.047	.022	.056	.015	.024	.024	.027
December	.038	.052	.058	.057	.024	.014	.008	.016
Mean	.055	.045	.042	.041	.020	.020	.021	.029

TABLE X.—*Relative tendency of rain with each wind, Chicago*—Continued.

Month.	N.	NE.	E.	SE.	S.	SW.	W.	NW.
Warm.								
April	.032	.044	.039	.021	.020	.035	.041	.028
May	.046	.069	.034	.025	.037	.032	.019	.010
June	.047	.041	.039	.040	.063	.042	.041	.040
July	.057	.031	.065	.040	.042	.027	.035	.022
August	.049	.035	.014	.041	.036	.035	.045	.027
September	.038	.025	.025	.019	.032	.038	.052	.034
Mean	.045	.041	.036	.031	.038	.035	.039	.027
Year	.050	.043	.039	.036	.029	.027	.030	.028
Cold months	.045	.045	.049	.037	.020	.017	.012	.027
Medium months	.055	.040	.030	.034	.023	.031	.042	.033
Hot months	.050	.044	.038	.037	.045	.034	.035	.025

HEAVINESS OF PRECIPITATION WITH EACH WIND.

The question arises: Are the lake winds likely to give a heavier fall of rain during a storm than the land winds? Table XI exhibits precipitation by months according to the amount of rain falling at any observation. It will be seen that rains up to 1.00 inch show very slight influence from the wind direction. Above 1.00 inch, however, there seems to be a tendency for the heavier rains to come with the lake winds.

TABLE XI.—*Rain with different winds, Chicago.*

Month.	0 to .25 inch.								.26 to .50 inch.							
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	N.	NE.	E.	SE.	S.	SW.	W.	NW.
January	.07	.04	.07	.09	.06	.04	.04	.04	.17	.18	.17	.17	.16	.20	.14	.23
February	.04	.05	.05	.05	.04	.05	.05	.04	.18	.17	.20	.21	.14	.16	.14	.14
March	.03	.05	.07	.04	.05	.05	.04	.03	.16	.16	.22	.20	.17	.17	.14	.21
April	.04	.06	.05	.05	.06	.06	.06	.03	.18	.18	.20	.14	.19	.17	.19	.17
May	.05	.05	.05	.05	.05	.05	.05	.06	.19	.18	.16	.17	.20	.19	.14	.15
June	.05	.04	.05	.04	.06	.05	.05	.06	.17	.18	.16	.20	.19	.20	.22	.15
July	.05	.04	.04	.05	.04	.05	.03	.05	.19	.19	.17	.16	.21	.18	.....	.18
August	.03	.04	.03	.05	.06	.04	.04	.05	.19	.19	.....	.17	.19	.18	.....	.21
September	.07	.05	.05	.05	.04	.05	.04	.04	.....	.24	.....	.24	.21	.20	.18	.20
October	.04	.06	.03	.07	.06	.05	.03	.04	.19	.21	.20	.17	.17	.16	.18	.21
November	.06	.06	.07	.05	.05	.05	.03	.04	.20	.17	.....	.18	.16	.17	.21	.20
December	.05	.05	.05	.06	.04	.03	.02	.03	.17	.16	.19	.19	.18	.19	.16	.16
Mean	.05	.05	.05	.05	.05	.05	.04	.04	.18	.18	.19	.18	.18	.18	.16	.18

Month.	.50 to 1.00 inch.								Above 1.00 inch.							
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	N.	NE.	E.	SE.	S.	SW.	W.	NW.
January	.....	.27	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.65	.....	.....	.65
February	.....	.30	.....	.....	.30	.....	.29	.....	.....	.....	.68	.....	.68	.....	.....	.....
March	.25	.38	.46	.37	.37	.31	.....	.37	.59	.59	.69	.....	.....	.....	.....	.....
April	.30	.33	.44	.28	.29	.35	.36	.39	.....	.....	.60	.....	.....	.....	.....	.....
May	.37	.33	.27	.43	.43	.30	.33	.28	.....	1.13	.....	.....	.63	.70	.....	1.17
June	.32	.30	.35	.41	.41	.34	.39	.31	.....	.69	.....	.69	.63	.....	.....	.69
July	.35	.34	.40	.34	.37	.34	.42	.....	.72	.77	1.49	.80	.59	.98	.....	.....
August	.36	.30	.....	.40	.41	.39	.....	.39	.....	.67	.....	.61	.76	.78	.56	.....
September	.27	.29	.31	.36	.45	.32	.33	.....	1.13	1.01	.50	.79	.74	.52	.57	.61
October	.37	.32	.40	.32	.37	.35	.25	.42	.84	.83	.....	.61	.68	.61	.69	.....
November	.35	.34	.....	.31	.30	.31	.....	.32	.....	.52	.52	.....	.55	.....	.55	.....
December	.39	.40	.26	.33	.43	.40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean	.33	.33	.36	.36	.38	.34	.34	.35	.82	.78	.75	.70	.66	.72	.59	.78

INFLUENCE OF THE LAKE UPON DEW-POINT AND RELATIVE HUMIDITY.

The dew-point and relative humidity for 7 a. m. and 3 p. m. during January, May, and July of the years 1882–1886 at Chicago and Indianapolis were computed, and are given in Table XII and shown graphically in Fig. 6. The dew-point for July shows a slight increase with a lake wind, but the most marked effect is produced upon the relative humidity, especially at 3 p. m., during May and July, in which months the relative humidity at the two stations is 69 and 51 per cent., respectively, in May, and 67 and 45 per cent. in July.

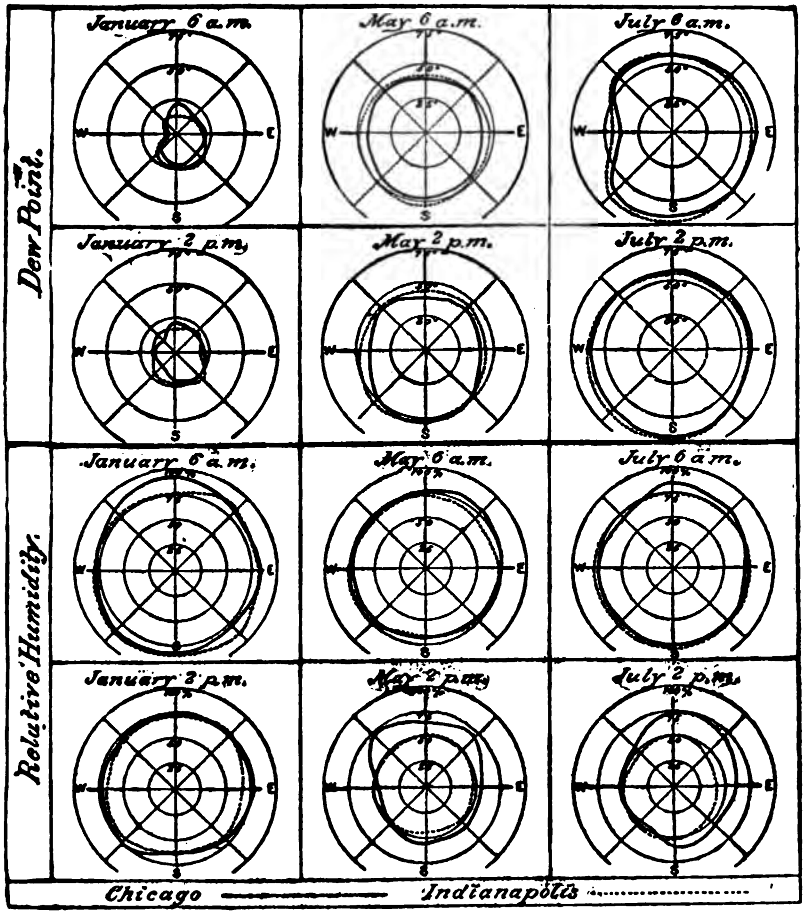


FIG. 6.—*Dew-point and relative humidity, with each wind, Chicago and Indianapolis.*

TABLE XII.—*Dew-point and relative humidity with different winds*, 1882, 1883, 1884, 1885, *and* 1886.

CHICAGO.

	N.		NE.		E.		SE.		S.		SW.		W.		NW.	
	°	%	°	%	°	%	°	%	°	%	°	%	°	%	°	%
January, 7 a. m.	21	93	18	83	22	85	19	79	23	83	15	83	4	79	10	83
3 p. m.	22	75	21	77	22	78	25	71	20	64	13	73	14	73	11	71
May, 7 a. m.....	39	77	42	79	42	76	46	70	49	70	46	70	40	72	40	73
3 p. m.....	39	65	43	69	41	55	48	57	53	55	49	50	39	46	43	69
July, 7 a. m.....	57	84	60	81	61	76	62	77	61	76	61	72	58	75	55	70
3 p. m.....	58	73	58	67	59	61	61	57	64	59	61	48	60	52	57	56

INDIANAPOLIS.

	N.		NE.		E.		SE.		S.		SW.		W.		NW.	
January, 7 a. m.	12	76	18	83	20	82	27	90	24	84	20	87	6	81	11	78
3 p. m.	18	71	22	78	19	66	28	73	21	63	21	68	14	67	17	68
May, 7 a. m.....	42	72	42	69	48	74	49	72	53	69	51	75	48	76	41	70
3 p. m.....	43	51	46	51	45	48	48	49	52	44	54	47	47	51	44	47
July, 7 a. m.....	57	75	57	73	58	71	61	76	65	79	65	79	64	79	58	75
3 p. m.....	57	50	57	45	57	41	61	47	65	53	66	53	63	50	57	45

LAKE AND WIND VELOCITY.

Table XIII contains the relative number of hours of wind from each direction with the mean velocity for the years 1890 and 1891,

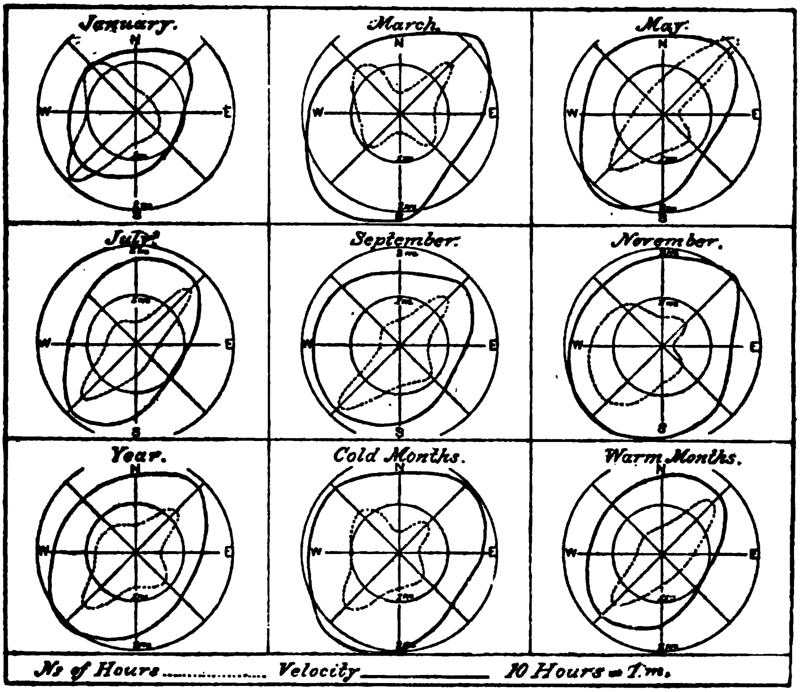


FIG. 7.—*Wind roses for* 1890 *and* 1891 (*Auditorium*).

and Fig. 7 presents each second month of the same in graphical form. The dotted lines in this figure contain the same kind of data that Fig. 1 exhibits, except that here they are for only two years, while in

Fig. 1 are the records for 18 years. A remarkable agreement will be found on comparing these wind roses. It will be seen from Fig. 7 that the general tendency is for a greater velocity with northeast and southwest winds, and this was to be expected, for it is in the northeast direction that the greater lake surface extends, and this would assist the wind because of less friction in these two directions. It is to be noted, however, that in addition to the lake influence there is pretty good evidence of a general tendency all over this part of the country for the winds to assume these directions, as well as a slightly greater velocity from them. This seems to be a well defined law, and while the southwest wind may be accounted for from the fact that it is in the direction of general currents, the northeast wind cannot be so accounted for and demands still further investigation, and one that would seem to be of much importance.

TABLE XIII.—*Hours and average miles from each direction,* 1890 *and* 1891.

Months.	N.		NE.		E.		SE.	
	Hours.	*Miles.*	*Hours.*	*Miles.*	*Hours.*	*Miles.*	*Hours.*	*Miles.*
January	46	12.3	46	15.3	47	9.5	61	10.0
February	45	13.0	80	17.2	28	16.4	67	15.7
March	47	16.0	145	21.8	76	17.0	89	14.8
April	66	18.3	211	19.7	73	16.2	85	13.6
May	74	15.5	207	19.1	33	12.9	77	11.3
June	36	13.2	155	14.8	94	12.2	123	11.8
July	45	17.1	152	17.6	48	11.0	104	9.7
August	68	14.3	147	15.5	65	10.8	110	8.8
September	55	14.9	142	18.0	63	13.4	90	12.8
October	96	15.5	97	15.7	42	13.2	90	14.0
November	58	17.6	66	20.3	19	13.8	53	16.6
December	50	17.6	62	19.4	17	18.4	92	16.8
Year	57	15.7	126	18.5	50	13.7	87	12.9
Cold months	47	15.5	83	19.5	42	17.3	77	15.8
Medium months	74	16.7	145	18.7	42	14.0	76	13.6
Warm months	51	14.9	149	16.5	68	11.9	107	10.8

Months.	S.		SW.		W.		NW.	
	Hours.	*Miles.*	*Hours.*	*Miles.*	*Hours.*	*Miles.*	*Hours.*	*Miles.*
January	65	12.4	188	15.4	104	18.2	133	12.8
February	70	19.3	131	21.7	103	20.0	94	20.1
March	38	22.0	99	23.6	84	18.0	122	15.9
April	73	19.6	98	25.2	57	16.4	46	16.8
May	76	17.2	150	21.0	59	16.2	50	16.0
June	62	14.6	101	17.0	60	13.8	38	12.4
July	66	14.6	155	18.4	67	13.7	55	13.8
August	62	13.8	130	17.4	46	14.0	74	13.0
September	84	15.6	171	18.6	38	17.8	43	16.0
October	70	16.1	133	21.0	78	16.0	112	15.7
November	81	18.9	160	20.7	150	18.6	119	17.3
December	113	18.8	195	24.1	101	17.8	101	17.3
Year	72	17.2	143	20.2	79	16.8	82	15.8
Cold months	71	20.0	153	21.8	98	18.6	112	17.8
Medium months	75	18.0	137	22.0	86	16.8	82	16.5
Warm months	69	14.7	139	17.9	53	14.8	53	13.8

MEAN VELOCITY DURING STORMS.

It would be interesting to ascertain whether this law holds for winds occurring during the time of storms. Table XIV has been prepared to show this effect. The corresponding wind roses (not reproduced) show a similar tendency to a greater velocity with southwest and northeast winds, though this effect is not as marked as in Fig. 7, possibly in part because the winds of Fig. 7 were all observed on the Auditorium tower, and for that reason may exhibit such effects more clearly.

TABLE XIV.—*Mean velocity of wind during rainfall according to direction*, 1872–'89.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
	Miles.	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*
January	11.1	12.5	8.1	8.6	8.3	12.7	11.0	10.4
February	8.8	12.1	11.0	9.1	8.6	11.8	13.6	9.9
March	14.1	13.1	11.6	10.7	10.3	11.8	12.1	11.3
April	12.2	11.5	12.0	8.6	10.6	10.6	9.9	10.5
May	12.4	12.4	9.1	8.1	7.8	9.8	8.8	8.7
June	10.7	7.7	7.2	5.8	8.7	9.5	7.2	8.5
July	9.4	7.9	7.2	6.6	7.7	8.2	6.5	7.1
August	11.1	9.4	7.6	6.5	8.0	7.3	6.6	6.5
September	11.1	11.0	10.1	9.0	8.7	8.6	9.0	8.1
October	11.4	11.5	6.9	8.0	11.0	12.0	10.3	9.7
November	9.7	13.8	7.8	10.3	9.4	11.3	11.0	11.5
December	9.0	11.5	10.0	8.4	9.4	11.7	10.2	8.7
Year	10.9	11.3	9.1	8.3	9.0	10.4	9.7	9.3
Cold months	10.8	12.3	10.2	9.2	9.2	12.0	11.7	10.1
Medium months	11.7	12.6	9.0	8.8	9.7	10.9	10.0	10.1
Warm months	10.6	9.0	8.0	7.0	8.3	8.4	7.3	7.6

LAND AND LAKE BREEZES.

Hourly observations of the velocity and direction of the wind have been made for a number of years, and these will enable us to determine quite accurately the occurrence of land and lake breezes. The existence of such breezes was demonstrated a good many years ago. One of these investigations will be found in Signal Service Note VI, p. 19, prepared in 1883. The illustration giving the hourly wind direction as computed by Lambert's formula for the months June–September, 1882, is here given in Fig. 8. Table XV contains hourly[*] wind directions for 1884, 1889, 1890, and 1891, and the last six months of 1888, and Fig. 9 is a graphic presentation of a portion of this table.

TABLE XV.—*Hourly wind directions.*

Year and months.	24.	1.	2.	3.	4.	5.	6.	7.
1884.	°	°	°	°	°	°	°	°
January	s 82 w	s 80 w	s 75 w	s 75 w	s 73 w	s 85 w	s 89 w	s 89 w
February	s 88 w	s 69 w	n 84 w	s 86 w	n 86 w	n 86 w	n 78 w	n 74 w
March	n 29 w	n 34 w	n 32 w	n 46 w	n 51 w	n 26 w	n 19 w	n 2 w
April	n 27 e	n 18 e	n 9 e	n 13 e	n 7 e	n 19 e	n 26 e	n 26 e
May	n 16 w	n 43 w	n 37 w	n 65 w	n 65 w	n 83 w	s 78 w	s 89 w
June	n 54 e	n 75 e	n 72 e	n 82 e	n 79 e	n 49 e	n 36 e	n 29 e
July	n 17 e	n 33 w	n 23 w	n 24 w	n 35 w	n 43 w	n 28 w	n 21 w
August	s 29 e	s 3 e	s 78 w	s 40 w	s 40 w	s 31 w	s 53 w	s 60 w
September	s 9 w	s 16 w	s 10 w	s 15 w	s 13 w	s 47 w	s 37 w	s 19 w
October	s 27 w	s 49 w	s 56 w	s 54 w	s 58 w	s 62 w	s 64 w	s 58 w
November	s 85 w	s 86 w	s 86 w	s 79 w	s 81 w	s 78 w	s 76 w	s 81 w
December	s 44 w	s 57 w	s 62 w	s 73 w	s 77 w	s 74 w	s 71 w	s 69 w

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[*] The hours are counted from 1 to 24, 24 being midnight.

TABLE XV.—*Hourly wind directions*—Continued.

Year and months.	8.	9.	10.	11.	12.	13.	14.	15.
1884.	o	o	o	o	o	o	o	o
January	s 88 w	s 87 w	s 86 w	s 80 w	s 77 w	s 73 w	s 72 w	s 70 w
February	n 78 w	n 75 w	n 71 w	s 89 w	n 62 w	s 79 w	s 52 w	s 81 w
March	n 2 e	n 5 e	n 9 e	n 69 e	n 62 e	n 43 e	n 29 e	n 17 e
April	n 10 e	n 21 e	n 20 e	n 29 e	n 29 e	n 28 e	n 29 e	n 29 e
May	s 89 w	n 75 w	n 62 w	n 13 w	n 4 w	n 21 w	n 17 w	n 3 w
June	n 47 e	n 40 e	n 34 e	n 39 e	n 37 e	n 36 e	n 36 e	n 38 e
July	n 46 w	n 29 w	n 16 e	n 24 e	n 63 e	n 66 e	n 74 e	n 76 e
August	s 70 w	s 45 w	s 50 w	n 20 e	n 37 e	n 53 e	n 42 e	n 62 e
September	s 20 w	s 21 w	s 29 w	s 20 w	s 48 w	s 38 w	s 28 w	s 23 w
October	s 60 w	s 67 w	s 67 w	s 77 w	s 84 w	s 81 w	s 79 w	s 70 w
November	s 78 w	s 74 w	s 75 w	n 89 w	s 79 w	s 75 w	s 79 w	s 75 w
December	s 69 w	s 67 w	s 76 w	s 74 w	s 72 w	s 63 w	s 44 w	s 48 w

Year and months.	16.	17.	18.	19.	20.	21.	22.	23.
1884.	o	o	o	o	o	o	o	o
January	s 70 w	s 67 w	s 65 w	s 80 w	s 80 w	s 79 w	s 78 w	s 79 w
February	s 87 w	n 39 w	n 53 w	n 48 w	n 73 w	n 85 w	n 85 w	n 83 w
March	n 17 e	n 2 w	n 9 w	n 24 w	n 28 w	n 29 w	n 26 w	n 34 w
April	n 32 e	n 37 e	n 45 e	n 43 e	n 24 e	n 15 e	n 25 e	n 24 e
May	n 3 w	n 84 e	n 84 e	n 73 e	s 86 e	s 68 e	s 86 e	s 36 e
June	n 35 e	n 32 e	n 11 e	n 20 e	n 25 e	n 20 e	n 42 e	n 49 e
July	n 75 e	n 32 e	n 29 e	n 24 e	n 30 e	n 23 e	n 23 e	n 27 e
August	n 45 e	n 61 e	n 68 e	n 72 e	n 58 e	n 72 e	n 79 e	s 77 e
September	s 14 w	s 14 w	s 3 w	s 2 e	s 4 e	s 2 e	s 2 w	s 7 w
October	s 71 w	s 51 w	s 30 w	s 41 w	s 32 w	s 36 w	s 39 w	s 52 w
November	s 75 w	s 62 w	s 67 w	s 82 w	s 83 w	s 88 w	s 84 w	s 85 w
December	s 58 w	s 60 w	s 64 w	s 61 w	s 56 w	s 59 w	s 60 w	s 53 w

Year and months.	24.	1.	2.	3.	4.	5.	6.	7.
1888.	o	o	o	o	o	o	o	o
July	n 83 e	s 71 e	s 33 e	s 54 e	s 37 e	s 37 e	s	s 71 e
August	s 51 w	s 75 w	n 82 w	s 80 w	s 67 w	s 73 w	s 50 w	s 60 w
September	s 30 e	s 13 w	s 46 w	s 42 w	s 42 w	s 38 w	s 35 w	s 32 w
October	s 70 w	s 67 w	s 60 w	s 63 w	s 65 w	s 69 w	s 63 w	s 73 w
November	s 85 w	s 86 w	s 86 w	n 88 w	s 78 w	s 78 w	s 82 w	s 85 w
December	s 73 w	s 80 w	s 71 w	s 75 w	s 72 w	s 74 w	s 76 w	s 81 w

Year and months.	8.	9.	10.	11.	12.	13.	14.	15.
1888.	o	o	o	o	o	o	o	o
July	s 49 e	s 14 e	s 75 e	s 78 e	n 59 e	n 62 e	n 69 e	n 51 e
August	s 32 w	s 51 e	s 34 w	n 82 w	s 32 e	s 59 e	s 63 e	n 79 e
September	s 54 w	n 83 w	n 70 w	n 59 w	n 45 e	n 49 e	n 50 e	n 51 e
October	s 63 w	s 73 w	s 53 w	s 47 w	s 57 w	s 42 w	s 79 w	s 45 w
November	s 85 w	s 83 w	n 81 w	n 76 w	n 52 w	n 50 w	n 35 w	n 16 w
December	s 77 w	s 67 w	s 66 w	s 66 w	s 59 w	s 66 w	s 63 w	s 55 w

Year and months.	16.	17.	18.	19.	20.	21.	22.	23.
1888.	o	o	o	o	o	o	o	o
July	n 42 e	n 45 e	n 77 e	n 66 e	n 64 e	n 83 e	e	s 84 e
August	n 65 e	n 22 e	s 45 e	s 13 e	s 24 e	s 18 w	s	s 28 w
September	n 60 e	n 58 e	n 79 e	s 10 e	s 83 e	s 38 e	s	s 23 w
October	s 86 w	n 45 e	s	s 82 w	s 71 w	s 85 w	s 72 w	s 69 w
November	n 41 w	n 35 w	n 58 w	n 66 w	n 72 w	n 75 w	n 80 w	n 75 w
December	s 62 w	s 64 w	s 67 w	s 73 w	s 70 w	s 74 w	s 75 w	s 75 w

TABLE XV.—*Hourly wind directions*—Continued.

Year and months.	24.	1.	2.	3.	4.	5.	6.	7.
1889.	°	°	°	°	°	°	°	°
January	s 56 w	s 54 w	s 61 w	s 61 w	s 58 w	s 52 w	s 49 w	s 65 w
February	n 72 w	n 81 w	n 81 w	n 85 w	s 86 w	s 88 w	s 76 w	s 70 w
March	n 62 w	n 75 w	n 60 w	n 41 w	n 40 w	n 38 w	n 28 w	n 26 w
April	s 77 w	n 77 e	n 9 e	n 23 w	n 33 w	n 13 w	n 35 w	n 36 w
May	s 84 w	n 63 w	n 74 w	n 69 w	n 60 w	n 45 w	n 34 w	n 38 w
June	s 11 e	s 60 w	n 66 w	s 41 w	s 41 w	s 42 w	s 49 w	s 67 w
July	s 17 e	s 18 e	s 51 w	s 30 w	s 47 w	s 33 w	s 39 w	s 65 w
August	s 9 w	s 30 w	s 26 w	s 37 w	s 47 w	s 46 w	s 53 w	s 56 w
September	s 42 w	s 44 w	s 60 w	s 54 w	s 43 w	s 50 w	s 58 w	s 53 w
October	n 24 e	n 5 e	n	n 30 w	n 40 w	n 40 w	n 52 w	n 49 w
November	s 84 w	s 83 w	s 77 w	s 61 w	s 65 w	s 74 w	n 87 w	s 77 w
December	s 58 w	s 53 w	s 45 w	s 45 w	s 59 w	s 60 w	s 65 w	s 59 w

Year and months.	8.	9.	10.	11.	12.	13.	14.	15.
1889.	°	°	°	°	°	°	°	°
January	s 63 w	s 68 w	s 72 w	s 80 w	s 82 w	s 74 w	s 72 w	s 66 w
February	s 74 w	s 76 w	s 83 w	s 66 w	s 87 w	s 86 w	n 86 w	n 82 w
March	n 38 w	n 45 w	n 58 w	n 16 w	n 10 e	n 15 w	n 1 e	n 15 e
April	n 49 e	n 22 w	n 56 e	n 60 e	n 72 e	n 72 e	n 64 e	n 71 e
May	n 4 w	n 22 w	n 47 w	n 14 w	n 28 w	n	n 2 w	n 75 e
June	s 55 w	n 78 w	n 22 w	n 35 e	n 8 e	s 45 w	n 65 e	s 81 e
July	s 50 w	n 82 w	n 62 e	n 81 e	n 57 e	n 51 e	n 50 e	n 34 e
August	s 70 w	s 53 w	s 54 w	s 36 w	s 7 w	s 24 e	s 7 e	s 14 e
September	s 57 w	s 54 w	s 70 w	s 74 w	s 76 w	n 9 w	n 45 e	s 64 e
October	n 28 w	n 13 w	n	n 2 e	n 20 e	n 13 e	n 34 e	n 33 e
November	s 87 w	s 85 w	s 85 w	n 86 w	n 58 w	n 42 w	n 68 w	n 52 w
December	s 70 w	s 72 w	s 60 w	s 56 w	s 71 w	s 55 w	s 40 w	s 50 w

Year and months.	16.	17.	18.	19.	20.	21.	22.	23.
1889.	°	°	°	°	°	°	°	°
January	s 65 w	s 62 w	s 52 w	s 51 w	s 48 w	s 61 w	s 52 w	s 56 w
February	n 84 w	s 87 w	n 87 w	n 88 w	n 87 w	n 87 w	n 83 w	n 89 w
March	n 13 e	n 16 e	n 70 w	n 63 w	n 72 w	n 4 e	n 30 w	n 35 w
April	n 85 e	s 86 e	n 88 e	n 79 e	s 74 e	s 71 e	s 62 e	s 45 e
May	n 84 e	n 31 e	n 54 e	n 71 e	n 52 e	n 45 w	n 20 e	n 75 e
June	n 51 e	n 15 e	n 68 e	n 89 e	n 86 e	s 77 e	s 55 e	s 54 e
July	n 43 e	n 59 e	n 68 e	n 78 e	n 77 e	s 69 e	s 54 e	s 28 e
August	s 46 e	s 37 e	s 39 e	s 31 e	s 34 e	s 17 e	s 14 e	s 1 w
September	n 31 w	n 13 w	s 9 e	s 19 e	s 5 e	s 5 e	s 15 w	s 14 w
October	n 23 e	n 35 e	n 57 e	n 74 e	n 58 e	n 57 e	n 67 e	n 60 e
November	n 26 w	n 35 w	n 28 w	n 33 w	n 68 w	s 80 w	n 88 w	n 86 w
December	s 37 w	s 39 w	s 46 w	s 33 w	s 36 w	s 41 w	s 45 w	s 45 w

Year and months.	24.	1.	2.	3.	4.	5.	6.	7.
1890.	°	°	°	°	°	°	°	°
January	s 84 w	s 64 w	s 72 w	s 74 w	s 63 w	s 70 w	s 89 w	s 53 w
February	s 81 w	w	n 81 w	n 84 w	n 45 w	s 86 w	s 88 w	n 86 w
March	s 71 w	w	n 52 w	n 60 w	n 19 w	n 19 w	n 53 w	n 47 w
April	n 84 e	s 86 e	s 82 e	e	s 85 e	s 86 e	n 70 e	n 64 e
May	w	s 8 w	s 18 w	s 36 w	n 18 w	n 52 w	n 59 w	n 73 w
June	s 6 e	s	s 8 e	s	s 20 w	s 13 w	s 54 w	s 50 w
July	s 58 e	s 10 e	s 38 w	s 30 w	s 39 w	s 40 w	s 35 w	s 25 w
August	s 19 e	s 11 e	s 17 e	s	s 7 w	s 15 w	s [illegible]9 w	s 16 w
September	s 57 e	s 50 e	s 10 w	s 13 w	s 35 w	s 35 w	s 17 w	s 8 w
October	s 76 w	s 79 w	s 77 w	s 80 e	s 65 e	s 63 e	s 64 e	s 59 e
November	s 83 w	s 85 w	n 78 w	s 83 w	s 80 w	s 80 w	n 87 w	n 83 w
December	s 74 w	s 80 w	s 83 w	s 87 w	n 88 w	n 77 w	n 61 w	n 65 w

TABLE XV.—*Hourly wind directions*—Continued.

Year and months.	8.	9.	10.	11.	12.	13.	14.	15.
1890.	°	°	°	°	°	°	°	°
January	s 42 w	s 45 w	s 59 w	s 43 w	s 54 w	s 45 w	s 32 w	s 51 w
February	s 56 w	s 79 w	s 71 w	s 65 w	s 83 w	s 84 w	s 74 w	n 85 w
March	n 51 w	s 61 w	n 78 w	s 23 w	n 71 w	n 54 w	n 32 w	n 28 w
April	n 76 e	n 83 e	n 82 e	n 79 e	n 61 e	n 58 e	n 57 e	n 63 e
May	n 83 w	s 83 w	w	w	s 45 w	s 83 w	s 57 w	n 56 w
June	s 65 w	s 24 w	s 25 w	s 13 w	s 10 e	s 65 e	s 88 e	s 80 e
July	s 29 w	s 11 w	s 2 w	s 1 e	n 79 e	s 83 e	s 67 e	s 69 e
August	s 21 e	s 14 w	s 43 e	s 39 e	n 73 e	n 78 e	n 83 e	n 81 e
September	s 20 w	s 4 w	s 50 e	s 55 e	n 52 e	n 48 e	n 48 e	n 66 e
October	s 67 e	s 65 w	s 79 e	s 72 e	n 25 e	n 36 e	n 45 e	n 53 e
November	n 87 w	n 83 w	s 88 w	s 82 w	s 76 w	s 83 w	s 76 w	n 85 w
December	n 65 w	n 87 w	s 80 w	s 77 w	n 67 w	n 74 w	n 60 w	s 86 w

Year and months.	16.	17.	18.	19.	20.	21.	22.	23.
1890.	°	°	°	°	°	°	°	°
January	s 61 w	s 60 w	s 71 w	s 86 w	s 85 w	s 85 w	s 83 w	s 86 w
February	s 85 w	w	s 79 w	s 86 w	s 84 w	n 82 w	s 55 w	s 67 w
March	n 13 w	n 7 w	n 22 e	n 5 w	n 68 w	s 23 e	s 67 e	s 32 e
April	n 61 e	n 57 e	n 71 e	n 66 e	n 74 e	n 72 e	n 76 e	n 76 e
May	s 29 e	w	s 27 e	s 18 e	s 34 e	s 50 e	s 55 e	s 16 e
June	s 69 e	s 56 e	s 51 e	s 58 e	s 58 e	s 51 e	s 37 e	s 24 e
July	s 78 e	s 89 e	s 86 e	s 85 e	s 57 e	s 56 e	s 72 e	n 50 e
August	n 79 e	n 88 e	s 79 e	s 58 e	s 47 e	s 54 e	s 42 e	s 51 e
September	n 51 e	n 66 e	n 82 e	n 82 e	n 71 e	n 82 e	n 89 e	s 87 e
October	n 38 e	n 36 e	n 22 e	s 2 e	n 14 e	n 21 e	s 45 e	n 45 w
November	s 74 w	s 89 w	s 79 w	s 68 w	s 66 w	s 60 w	s 71 w	s 81 w
December	s 66 w	s 86 w	s 69 w	s 87 w	s 83 w	s 79 w	s 84 w	s 88 w

Year and months.	24.	1.	2.	3.	4.	5.	6.	7.
1891.	°	°	°	°	°	°	°	°
January	n 82 w	s 81 w	n 85 w	n 84 w	s 65 w	s 68 w	s 73 w	s 88 w
February	s 77 w	s 72 w	s 66 w	s 74 w	s 65 w	s 70 w	s 58 w	s 54 w
March	s 37 e	e	n 82 e	s 87 e	n 63 e	n 47 e	n 51 e	n 53 e
April	n	n 32 e	n 58 e	n 11 e	n 32 w	n 40 w	n 44 w	n 39 w
May	n 86 e	n 13 e	n 15 e	n 72 e	n 56 e	n 18 e	n 4 e	n 30 e
June	s 65 e	s 70 e	s 47 e	s 71 e	n 79 e	n 79 e	n 69 e	n 60 e
July	s 45 w	s 45 w	s 53 w	s 41 w	s 49 w	s 56 w	s 66 w	s 87 w
August	s 81 w	s 86 w	s 87 w	s 77 w	s 79 w	s 70 w	s 75 w	s 87 w
September	s 18 w	s 10 w	s 15 w	s 24 w	s 36 w	s 44 w	s 44 w	s 53 w
October	s 66 w	s 72 w	s 73 w	n 87 w	n 81 w	s 82 w	s 86 w	s 72 w
November	s 63 w	s 55 w	s 78 w	s 63 w	s 70 w	s 69 w	s 74 w	n 88 w
December	s 50 w	s 38 w	s 37 w	s 35 w	s 33 w	s 31 w	s 33 w	s 33 w

Year and months.	8.	9.	10.	11.	12.	13.	14.	15.
1891.	°	°	°	°	°	°	°	°
January	n 86 w	s 81 w	n 89 w	w	n 88 w	n 88 w	n 65 w	n 68 w
February	s 61 w	s 57 w	s 59 w	s 66 w	s 68 w	s 54 w	s 45 w	s 49 w
March	n 75 e	n 79 e	n 76 e	n 64 e	n 37 e	n 54 e	n 43 e	n 55 e
April	n 32 w	n 18 e	n 22 w	n 84 w	n 74 e	n 83 e	n 76 e	e
May	n 51 e	n 36 e	n 31 e	n 35 e	n 56 e	n 60 e	n 63 e	n 69 e
June	n 72 e	s 83 e	n 85 e	s 69 e	s 80 e	s 84 e	n 81 e	n 72 e
July	s 81 w	n 81 w	n 45 e	n 77 e	n 54 e	n 84 e	n 86 e	s 86 e
August	n 81 w	s 51 w	n 80 e	n 69 e	s 80 e	n 69 e	n 83 e	s 82 e
September	s 44 w	s 54 w	s 20 w	s 29 w	s 8 e	s 22 e	s 30 e	s 32 e
October	s 75 w	s 65 w	s 46 w	s 45 w	s 81 w	n 49 w	n 62 w	n 6 e
November	n 84 w	s 75 w	s 76 w	s 56 w	s 72 w	s 88 w	s 89 w	s 27 w
December	s 33 w	s 28 w	s 27 w	s 22 w	s 22 w	s 19 w	s 19 w	s 11 w

TABLE XV.—*Hourly wind directions*—Continued.

Year and months.	16.	17.	18.	19.	20.	21.	22.	23.
1891.	°	°	°	°	°	°	°	°
January	s 85 w	s 80 w	s 56 w	s 62 w	s 65 w	s 63 w	s 78 w	s 84 w
February	s 60 w	s 51 w	s 62 w	s 63 w	s 75 w	s 65 w	s 79 w	s 76 w
March	n 35 e	n 28 e	n 45 e	n 32 e	n 45 e	n 45 e	n 74 e	n 85 e
April	n 66 e	n 73 e	n 76 e	n 50 e	n 70 e	n 67 e	n 89 e	n 74 e
May	s 87 e	s 86 e	s 88 e	s 86 e	s 85 e	s 67 e	s 54 e	s 40 e
June	n 63 e	n 78 e	n 86 e	s 85 e	s 83 e	s 89 e	s 77 e	s 81 e
July	s 88 e	s 81 e	s 63 e	s 43 e	s 30 e	s 3 w	s 5 e	s 1 e
August	s 82 e	n 84 e	n 87 e	s 62 e	s 47 e	s 45 e	s 15 w	s 58 w
September	s 30 e	s 35 e	s 18 e	s 27 e	s 2 e	s 6 e	s 10 w	s 10 w
October	s 63 w	s 45 w	s 83 w	s 80 w	s 81 w	s 74 w	s 78 w	s 72 w
November	s 2 e	s 40 w	s 76 w	s 51 w	s 42 w	s 65 w	s 66 w	s 74 w
December	s 3 w	s 3 w	s 15 w	s 2 w	s 14 w	s 29 w	s 37 w	s 42 w

The theory of these winds, and one almost universally accepted, is that during the day the land surface becomes heated considerably above that of water and there arises in the afternoon a tendency for the air to flow from above the water to the land, while at night the reverse action takes place, the land is greatly cooled by radiation to space and the air tends to flow in the contrary direction. This view makes the winds an aspiration effect, and this is known to be not wholly true, since on the shore of the ocean the sea breeze is seen to create a ripple first in the offing, and this ripple gradually approaches the land.

If these winds are merely aspiration airs, we would naturally expect that the velocity would be greatly diminished, especially if the land or lake breeze is opposite to the general trend of the wind, for, in one sense, such a breeze would have to first overcome the ordinary wind before it could flow at all in an opposite direction. It is to be noted that these land and lake breezes have only a very slight difference in their velocity.

There can be no doubt whatever of the existence of marked winds of this character during the warm months. On turning to Fig. 9, we see that from January to March and from October to December the general trend of the wind is from the west to east. According to the ordinary theory the land does not change its temperature so as to become opposite that of the water, but always remains cooler during the cold months, and, as a result, the ordinary trend of the wind is not changed. During the remaining months, however, the land and lake breezes are very marked. There is only one apparent exception, and this serves to emphasize the lake influence. It will be seen that in many of the warmer months there is a well marked lake breeze at all hours of the day. This would be due to the fact that the air above the lake surface continues throughout the 24 hours slightly cooler than that above the land. The greatest interest attaches in this question. The height of the land and lake breezes above the surface of both, the hours of change, and the velocity at different heights, with many other questions, are of great importance.

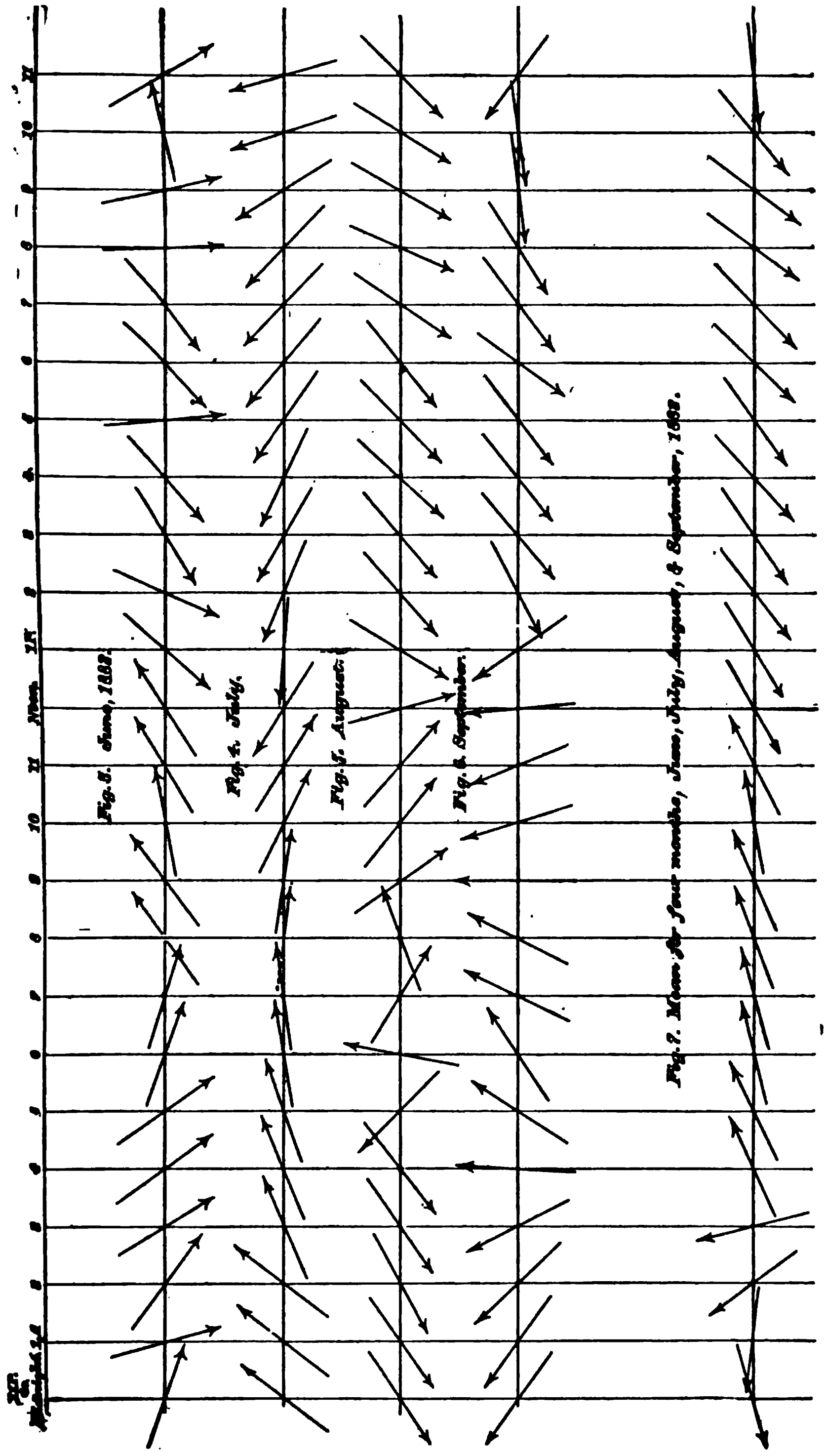


FIG. 8.—*Land and lake breezes, June–September,* 1882.

It is probably safe to say that a free balloon, if descending near the center of the lake during the warm season and in the afternoon, would be certainly driven landward at a velocity of 10 to 20 miles per hour.

These are the principal effects due to the lake influence though other minor effects will be noted later on. We will now pass to the second great division, or the general and average conditions of the meteorologic elements and the sharper fluctuations brought about by the passage of storms and high areas, warm and cold waves, etc.

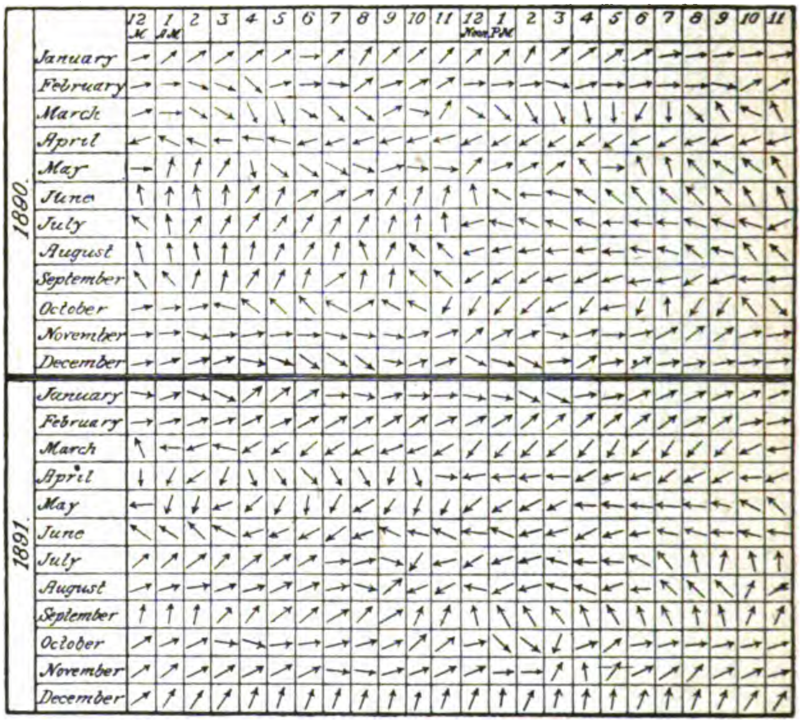
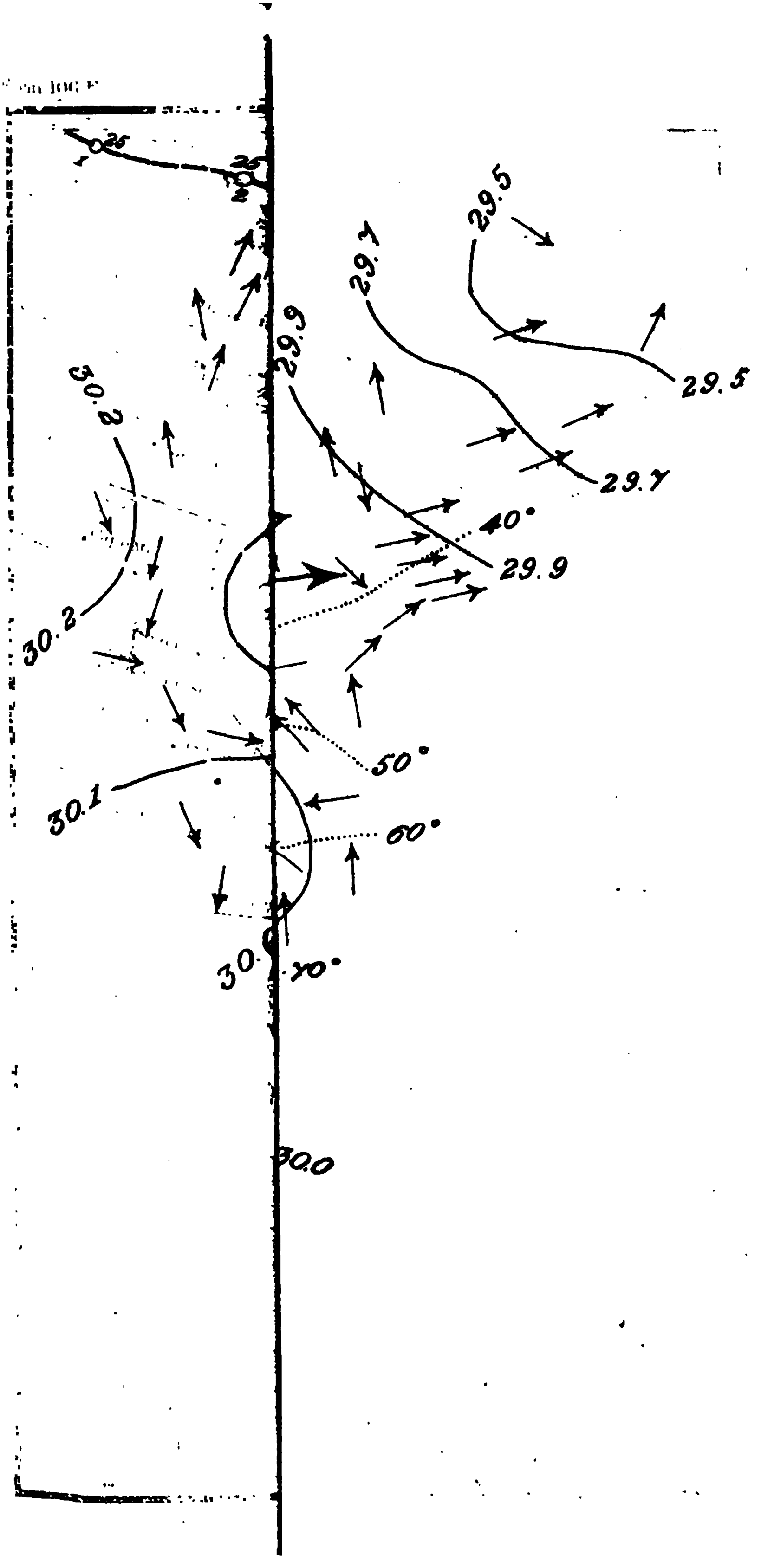


FIG. 9.—*Land and lake breezes.*

THE PRESSURE OF THE AIR.

The most important factor determining the occurrence of storms, cold waves, and other weather changes is what is commonly called the "barometer reading," or "barometer" for short. The barometer measures the pressure, or, more strictly speaking, the weight of the air.

The greatest advances in meteorology have been made by comparing, after they have been reduced to a common plane, the readings of barometers at stations some distance apart over a large region. In this way it has been found that isobars, or lines joining equal


25
25
29.5
29.7
29.9
30.2
29.5
29.7
40°
29.9
30.2
50°
30.1
60°
30.0
70°
30.0

barometer readings at sea level, map out larger or smaller oval spaces. These ovals, especially in the colder months and in latitudes above the tropics, are quite regular and wide extended. They represent what may be designated elevations or "highs" in the atmosphere, where the pressure is relatively high; or hollows, "lows," where the pressure is relatively low.

There is given in Fig. 10 a chart or weather map indicating the state of pressure, temperature, and wind direction at 8 p. m. (Eastern time) on March 27, 1890. It will be remembered that just at this time severe tornadoes were raging in Kentucky, and this gives an added interest to this map. It will be seen that the full lines or isobars inclose an oval space central over Illinois. These lines also map out the wind arrows, which are seen to point in a direction counter-clock-wise about the low center. The dotted temperature lines, or isotherms, show a well marked rise in the front of the storm and a similar fall in the rear. These characteristics will be found to be a general law as applied to storms, and the contrary is true of high areas. That is, the wind has a tendency to flow outward from the center of a high area, and their directions go about the oval with the hands of a clock. The air in front is much cooled and dry, while in the rear it is heated and becoming moist.

MEAN TEMPERATURE AT CHICAGO.

The temperature observations at Chicago began in July, 1832, at Fort Dearborn, a station near Lake Michigan. These were continued till December, 1836, after which month there is a gap till November, 1859, relieved only by six months observations during 1844 and all of 1857. These observations were made with every kind of exposure, and generally at 7 a. m., 2 p. m., and 9 p. m., until November, 1870, when the Signal Service record begins. The shelter of the Signal Service was placed at north windows of rather high buildings until January 1, 1887, when they were transferred to the roof. On February 1, 1890, the shelter was placed on the Auditorium building, at a height of 241 feet above the ground, giving by far the best exposure thus far obtained.

The hours of observation have been changed from time to time. Until November, 1879, they were mostly at 7.35 a. m., 4.35 and 11 p. m., Washington time, or 50 minutes earlier than Chicago time. From November, 1879, to July, 1888, they were at 7 a. m., 3 and 11 p. m., and since July, 1888, they have been taken at 8 a. m. and 8 p. m. During nearly the whole time the daily extremes have been observed by self-registering maximum and minimum thermometers, and since July, 1888, the mean temperature used in publications has been the $\frac{\text{max.} + \text{min.}}{2}$. Until July, 1881, daily observations were also made at

7 a.m., 2 and 9 p.m., local time. A careful study of all these records has shown that up to July, 1888, the mean of the three telegraphic observations has differed but very slightly from the mean obtained from $\frac{7+2+9+9}{4}$. Since July, 1888, the mean of the $\frac{8+8}{2}$ has been about a degree below the true mean, and the mean of the maximum and minimum has been about a half degree too high. It will thus be seen that a mean of the four $\frac{8 \text{ a. m.} + 8 \text{ p. m.} + \text{max.} + \text{min.}}{4}$ would give a much nearer approximation, generally speaking, than the mean maximum and minimum alone. There is, however, a slight complication which tends to cause the minimum to read too low, and this amount is not always constant. It seems advisable, for the present at least, to take the mean of the maximum and minimum, and to remember that this is liable to be a half degree too high. The error from this source, as will be seen presently, is small as compared with other errors.

It would be very interesting and of considerable value in discussing temperatures for an extended period, if we could obtain interpolated values for the time during which there are no records. This could be done with considerable accuracy if we had a long series of observations at a neighboring station which lapped over those at Chicago. Unfortunately there are no records of this description near Chicago, but we have a continuous series at two or more stations which overlap each other, and by using these it has been possible to interpolate a series of values and to make a complete record from 1830 to 1891. In Table XIX, wherever a record has been kept at Chicago, the temperature is given to the nearest tenth of degree, but in all interpolated values only the nearest degree is given.

It is important to settle upon a definite exposure to which to reduce all the readings, if possible. The best of all the exposures is undoubtedly the last, in the Auditorium building, where the thermometers are 241 feet above ground, and the attempt has been made to compute interpolated values uniform with those made since February, 1890. It should be noted, however, that these temperatures are not considered to apply strictly to portions of the city at some distance from the lake shore and on the street. The temperature of the air that we wish to obtain is that of a considerable stratum passing over the city, and unaffected by disturbing radiations or reflections. At Chicago, however, the presence of the lake complicates the question of the true air temperature very much, and it is probable that differences of 5° to 8° could be found in properly exposed thermometers, I mean at some distance above the street, especially during the early evening.

It is thought by some that the exposure of a thermometer above the roof of a building is objectionable because the highly heated tin roof and the heat escaping from the lower rooms would tend to raise the temperature, but experience has shown that the most important consideration is a perfect natural ventilation, and nearly everything else should be sacrificed for that. Still others think that the temperature needed is that at the level of the head on the sidewalk, but here we meet with a serious difficulty, in that in summer the temperature on the south side of the street is much lower than that on the north side, and in many cases it is lower even than that of a properly exposed thermometer.

It would appear that the earliest records, namely, those at Fort Dearborn, correspond fairly well with the present exposure though they may be very slightly lower. There were no large buildings about, and the exposure near the lake was quite satisfactory. The temperatures for the colder months, 1861–1865, seem to be a little too low. I have followed Mr. Schott in all cases, though the discrepancies between different series of observations in the city are often quite large. To show some of these I have drawn off Tables XVI and XVII.

TABLE XVI.—*Temperature at 7 a. m., 2 and 9 p. m., at different places in Chicago.*

Month.	7.	2.	9.	Mean.	Place.	Month.	7.	2.	9.	Mean.	Place.
1862.											
	°	°	°	°			°	°	°	°	
February	20.3	27.1	23.0	23.3	U.	September	64.4	71.5	66.0	67.0	U.
Do	14.3	25.5	17.0	18.4	B.	Do	56.3	70.3	58.0	60.6	B.
March	32.7	37.0	34.1	34.5	U.	October	51.9	59.6	54.1	54.9	U.
Do	26.4	34.0	29.3	29.7	B.	Do	42.6	56.8	45.4	47.5	B.
April	43.8	47.9	44.7	45.3	U.	November	34.8	39.1	36.2	36.6	U.
Do	37.4	47.9	38.8	40.7	B.	Do	28.1	39.3	30.6	32.1	B.
August	72.0	77.3	72.8	73.7	U.	December	29.7	36.8	31.3	32.3	U.
Do	65.9	77.5	64.6?	68.1	B.	Do	24.5	34.9	26.9	28.3	B.
1867.											
February	26.5	37.3	31.4	31.6	R.	July	69.5	79.1	71.5	72.9	R.
Do	24.9	36.6	29.2	30.0	B.	Do	72.2	82.3	69.3?	73.3	B.
March	26.5	38.1	29.0	30.6	R.	August	70.4	80.8	73.7	74.6	R.
Do	24.8	34.7	27.1	28.4	B.	Do	71.4	85.1	70.4?	74.3	B.
April	43.4	53.4	44.6	46.5	R.	September	62.1	75.6	66.9	67.9	R.
Do	44.5	55.1	43.2?	46.5	B.	Do	63.2	77.2	63.7	67.0	B.
May	48.7	56.7	48.4	50.6	R.	October	51.3	63.0	56.6	56.9	R.
Do	49.5	57.6	48.0?	50.8	B.	Do	49.6	65.3	53.1	55.3	B.
June	68.9	78.2	70.2	71.9	R.	December	27.1	33.2	29.1	29.6	R.
Do	72.2	84.2	67.8?	73.0	B.	Do	23.9	33.0	27.3	27.9	B.
1868.											
January	14.6	23.9	19.7	19.5	R.	July	78.2	86.4	78.7	80.5	R.
Do	11.4	24.1	15.0	16.4	B.	Do	79.7	89.7	76.8?	80.8	B.
February	19.4	33.3	27.2	26.8	R.	August	69.2	79.0	70.9	72.5	R.
Do	15.5	32.1	21.5	22.6	B.	Do	68.1	82.3	67.1?	71.2	B.
March	38.2	50.5	43.2	43.8	R.	September	58.7	70.1	60.9	62.6	R.
Do	36.0	49.6	39.4	41.1	B.	Do	56.8	70.0	57.0	60.0	B.
April	42.0	51.5	44.3	45.5	R.	October	49.4	58.0	50.3	52.0	R.
Do	39.2	52.0	41.0	43.3	B.	Do	46.0	56.7	47.8	49.6	B.
May	52.9	60.5	52.7	54.7	R.	November	38.3	46.2	41.4	41.8	R.
Do	51.3	60.5	51.7	53.8	B.	Do	29.9	40.3	33.1	34.1	B.
June	63.1	72.5	65.2	66.5	R.	December	22.0	29.5	24.5	25.1	R.
Do	63.2	76.2	61.3?	65.5	B.	Do	16.6	25.4	19.0	20.0	B.

NOTE.—U., University; B., Brooks; R., Randolph street.

TABLE XVII.—*Temperature recorded at different localities in Chicago.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Locality.
	°	°	°	°	°	°	°	°	°	°	°	°	
1862....	23.0	23.4	34.5	45.3	53.2	62.3	73.1	73.7	67.0	54.9	36.6	32.3	University.
1862....	18.2	18.4	29.8	40.7	50.5	57.0	68.0	68.2	60.6	47.6	32.2	28.3	Brooks.
1863....	33.5	......	35.0	......	......	......	......	......	......	......	......	......	University.
1863....	30.6	24.6	28.8	41.9	52.7	......	65.6	65.6	......	......	......	......	Brooks.
1864....	......	......	......	......	58.9	......	......	......	......	......	......	......	University.
1864....	......	......	......	......	52.5	......	......	......	......	......	......	17.8	Brooks.
1867....	19.9	31.6	30.6	46.5	50.6	71.9	72.9	74.6	67.9	56.9	44.8	29.6	Randolph st.
1867....	19.6	30.0	28.4	46.5	50.8	73.0	73.3	74.3	67.0	55.3	42.2	27.9	Brooks.
1868....	19.5	26.8	43.8	45.5	54.7	66.5	80.5	72.5	62.6	52.0	41.8	25.1	Randolph st.
1868....	16.4	22.6	41.1	43.3	53.8	65.5	80.8	71.2	60.0	49.6	34.1	20.0	Brooks.
1869....	33.4	31.5	32.0	47.3	54.6	65.2	73.0	73.1	66.8	45.6	35.8	30.2	Randolph st.
1869....	29.2	27.2	27.0	43.0	51.6	63.4	69.4	71.0	63.0	40.8	31.9	26.9	Brooks.
1870....	27.5	29.9	34.9	51.4	64.8	71.3	78.8	74.7	70.0	56.2	43.2	27.6	Randolph st.
1870....	24.3	25.2	30.1	45.5	60.0	67.3	74.8	70.6	67.4	54.1	41.4	26.5	Brooks.
1871....	30.9	30.2	41.2	51.2	56.7	66.8	73.0	72.7	61.0	......	35.0	20.0	Signal Service.
1871....	28.8	30.1	42.4	53.3	59.8	71.6	77.1	75.9	......	......	......	......	University.
1871....	27.0	28.6	40.5	48.6	58.0	68.4	74.0	73.3	61.6	56.2	36.0	21.7	Brooks.
1871....	27.1	28.4	39.0	49.0	56.9	63.3	70.9	71.8	60.4	53.4	34.2	19.5	Evanston.
1872....	23.0	25.5	27.6	48.7	56.3	69.3	71.7	72.1	64.0	50.2	31.9	19.1	Signal Service.
1872....	......	27.3	27.1	48.2	57.2	70.4	73.1	72.4	64.6	51.8	32.7	19.7	University.
1872....	23.2	25.9	28.7	47.3	60.5	70.0	73.5	72.9	67.7	50.8	31.2	19.3	Brooks.
1872....	21.9	25.2	27.4	......	56.0	68.9	72.2	73.5	65.4	50.3	31.1	17.5	Evanston.
1873....	20.4	24.1	34.3	43.0	53.8	70.3	70.8	72.1	62.1	48.9	34.3	32.0	Signal Service.
1873....	20.3	23.7	31.6	......	......	......	......	......	......	......	......	......	University.
1873....	19.6	21.7	33.2	42.3	54.0	70.5	72.2	74.3	62.9	47.0	31.8	30.0	Brooks.
1873....	18.1	22.0	33.0	42.0	52.0	65.2	70.6	72.6	62.3	46.7	......	......	Evanston.

Mr. Schott deemed it the wisest to take the mean of discordant observations at Chicago. Most of the discordances are probably due to the fact that some of the exposures were much nearer the lake than others. One interesting fact is brought out in Table XVI, in that oftentimes the 9 p. m. observation, ordinarily very near the mean for the day, and always higher than that at 7 a. m., is frequently lower than the 7 a. m. This occurs in the summer months almost invariably, for example, August, 1862, —1.3°; April, 1867, —1.3°; May, —1.5°; June, —3.4°; July, —2.9°; August, —1.0°. 1868: June, —1.9°; July, —2.9°; August, —1.0°. Now this anomaly might be due to the fact that the sun struck the thermometer in the early morning, but it is more probable that this exposure was near the lake and near the ground, if so, the lake breeze would tend to cool off the air near the lake and near the ground very rapidly, but, as morning approached, the land breeze would tend to heat up the air very slightly, and this effect would be heightened from the fact that the sun was shining at the 7 a. m. observation. Whatever the explanation, the fact is a most interesting one, and it has seemed advisable to here note the observations for others who are interested to make a study of them. The Auditorium temperature at 9 p. m. is 3° *higher* than at 7 a. m. during June, July, and August.

The Weather Service records previous to February, 1890, have a slight tendency to a too high temperature, especially when compared with those on the Auditorium. This may be shown approximately by comparing the observations at Chicago with those at Milwaukee, a station having very much the characteristics of the former. It should be noted, however, that the exposures at Milwaukee have changed from time to time, so that we have not there an invariable standard of comparison.

Table XVIII gives the mean temperature for January, February, March, November, and December, for each lustrum of 5 years, and also for May, June, July, August, and September.

TABLE XVIII.—*Mean temperature at Chicago and Milwaukee.*

Years.	Cold months.			Warm months.		
	Chicago.	Milwaukee.	Difference.	Chicago.	Milwaukee.	Difference.
	°	°	°	°	°	°
1856-1860	26.7	26.7	0.0	63.7	62.6	1.1
1861-1865	27.0	28.4	—1.4	63.3	63.0	0.3
1866-1870	29.4	27.3	2.1	67.0	62.8	4.2
1871-1875	29.5	24.9	4.6	66.1	63.1	3.0
1876-1880	33.3	28.5	4.8	67.0	63.8	3.2
1881-1885	30.2	26.3	3.9	65.2	61.8	3.4
1886-1890	30.6	26.0	4.6	67.4	62.4	5.0
Feb., 1890	*31.5	28.9	2.6	*63.8	62.2	1.6

*Auditorium.

The higher temperatures in the later years till February, 1890, are due to the fact that they were taken in window shelters. It might be thought advisable to apply some correction to the observed values in order to reduce them to a common exposure, but, on the whole, it has been decided to publish the records as they stand, and each one can apply a correction to suit himself.

Table XIX contains the mean temperature by months and years, made up as has just been described for 62 years, 1830–1891. A mean for 20, 21, and 21 years is made up at the foot of the table, and a final mean for the 62 years. These means, in most cases, are made out to the nearest tenth of a degree, though it should be noted that even the mean for 62 years does not represent the exact mean nearer than a half degree, probably in each month, and it would be impossible to say whether this was a half degree higher or lower than the Auditorium, but probably it is higher.

TABLE XIX.—*Mean temperature at Chicago.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean.
	°	°	°	°	°	°	°	°	°	°	°	°	°
1830	23	30	37	53	59	64	75	72	58	57	45	26	50
1831	18	20	37	43	57	69	72	70	61	49	32	15	45
1832	24	15	37	49	55	68	70.6	71.4	62.9	54.0	39.9	33.2	48.0
1833	29.7	27.6	33.3	50.5	60.1	63.6	72.4	70.3	64.0	45.5	39.8	34.1	49.2
1834	13.3	34.9	36.6	47.4	54.6	62.9	74.3	71.2	60.1	46.3	40.3	29.6	47.6
1835	28.1	14.0	32.0	42.5	54.6	63.1	67.1	65.2	54.3	47.9	34.2	24.8	44.0
1836	22.4	21.7	26.1	42.4	53.5	58.6	66.5	61.9	56.7	46.8	34.3	24.2	42.9
1837	23	25	28	38	48	61	66	65	59	50	40	26	44
1838	25	11	42	40	50	66	74	69	58	48	25	19	44
1839	29	28	35	53	54	61	73	66	54	59	31	27	48
1840	21	28	37	46	58	66	68	66	56	49	35	26	46
1841	22	23	35	41	55	67	69	67	57	48	37	27	46
1842	25	28	45	52	52	59	67	65	61	52	30	22	46
1843	26	13	16	45	53	65	71	67	65	44	33	32	44
1844	22	30.8	38.4	55.3	58.7	64	73.6	68	68.6	48	34	31	49
1845	35	33	39	51	58	68	75	70	63	51	37	23	50
1846	39	31	42	49	62	64	78	75	62	53	43	34	53
1847	20	30	32	47	53	65	76	67	64	51	41	30	48
1848	32	31	36	46	58	68	69	69	58	55	36	27	49
1849	22	21	38	42	50	66	70	66	62	50	45	22	46
1850	30	32	34	41	51	66	74	71	61	51	43	26	48
1851	28	35	40	45	53	64	71	69	67	51	36	23	49
1852	22	32	34	39	55	66	72	69	59	54	35	28	47
1853	29.7	29.1	37	45	52	67	68	68	62	50	39	30	48
1854	19	29	38	44	54	66	74	72	67	55	38	28	49
1855	26	18	31	48	56	62	70	67	62	46	37	22	45
1856	13	17	27	44	51	68	71	65	59	49	35	18.4	43
1857	10.7	30.6	27.9	34.6	50.4	63.1	71.5	67.7	62.8	48.9	29.9	31.4	44.2
1858	33	19	36	43	52	68	73	70	63	50	35	28	48
1859	27	29	38	41	55	62	74	71	59	49	32.9	15.7	46
1860	18.1	26.8	35.1	42.6	57.7	63.0	68.2	68.8	57.6	48.5	31.3	20.5	44.9
1861	21.9	29.4	31.7	43.0	49.1	63.2	66.2	68.5	61.0	48.4	34.1	28.4	45.4
1862	18.2	20.9	32.1	43.0	51.8	57.0	68.0	70.9	63.8	51.2	34.4	30.3	45.1
1863	33.5	20.6	31.9	41.9	52.7	59.4	65.6	65.6	56.9	39.9	33.4	26.3	44.3
1864	16.2	23.6	27.4	38.6	55.7	60.6	67.9	68.0	58.4	43.0	32.5	17.8	42.5
1865	17.2	26.0	32.2	42.5	51.3	66.1	62.9	65.2	66.3	46.6	35.4	20.2	44.3
1866	17.7	17.9	26.4	43.8	51.4	69.4	77.2	68.9	60.8	53.8	40.9	25.8	46.2
1867	19.9	30.8	29.5	46.5	50.7	72.4	73.1	74.5	67.4	56.1	43.5	28.8	49.4
1868	17.9	24.7	42.4	44.4	54.2	66.0	80.6	71.8	61.3	50.8	38.0	22.6	47.9
1869	31.2	29.3	29.5	45.2	53.1	64.3	71.2	72.1	64.9	43.2	33.9	28.6	47.2
1870	25.9	27.5	32.5	48.4	62.4	69.3	76.8	72.7	68.7	55.1	42.3	27.1	50.7
1871	30.9	30.2	41.2	51.2	56.7	66.8	73.0	72.7	61.0	54.6*	35.0	20.0	49.4
1872	23.0	25.5	28.1	47.2	56.1	69.2	72.2	71.8	63.9	50.1	31.5	19.0	46.5
1873	20.4	24.1	34.3	43.0	53.8	70.3	70.8	72.1	62.1	48.9	34.3	32.0	47.2
1874	28.9	31.4	36.5	38.6	59.3	70.5	74.8	71.8	66.4	53.0	40.3	33.5	50.4
1875	17.9	14.7	31.8	42.5	55.5	63.1	68.8	68.4	61.0	47.5	37.0	36.8	45.4
1876	33.0	31.8	33.9	46.5	59.0	67.5	73.5	73.5	61.1	48.8	39.3	20.0	49.0
1877	21.9	36.4	29.4	45.4	56.9	66.1	73.1	71.1	66.5	54.7	39.7	42.8	50.3
1878	31.2	35.7	44.3	52.2	55.5	65.4	74.8	73.6	65.9	52.0	43.1	23.7	51.4
1879	21.4	27.4	39.1	46.8	57.6	64.7	73.0	72.6	61.2	59.9	41.9	30.3	49.9
1880	40.1	34.6	37.9	48.5	64.2	69.9	72.4	72.4	62.5	50.8	31.4	23.0	50.6
1881	19.5	24.7	32.2	41.5	61.0	63.0	72.9	75.0	69.5	55.9	39.9	37.1	49.4
1882	28.3	38.2	38.3	45.9	51.7	63.6	68.6	71.2	65.0	56.5	41.7	20.0	49.6
1883	16.3	23.0	31.4	45.6	52.1	64.1	71.0	68.3	60.7	51.8	41.5	30.1	46.3
1884	19.2	27.7	34.2	44.3	56.7	65.0	69.2	68.8	68.9	56.4	39.6	28.4	48.2
1885	18.3	16.8	30.0	45.3	52.8	65.4	72.8	68.1	63.9	51.0	41.9	31.1	46.4
1886	21.4	28.1	36.1	49.1	57.0	66.0	71.4	72.4	66.1	56.6	38.2	25.0	49.0
1887	17.3	27.1	31.9	47.4	59.4	67.3	76.0	69.7	62.5	47.3	38.0	28.1	47.7
1888	15.1	23.0	30.5	45.4	52.6	67.4	72.6	69.4	59.8	49.1	41.6	32.2	46.6
1889	29.0	19.9	38.4	46.8	56.8	62.3	70.5	70.6	62.8	49.4	38.6	40.6	48.8
1890	30.8	32.4	29.5	45.6	53.4	70.2	72.1	67.6	60.4	51.4	41.9	30.6	48.8
1891	30.2	28.6	30.6	47.0	53.4	65.7	67.0	69.0	69.0	52.6	33.8	35.4	48.5
Mean, 1830 to 1849.	25	25	35	47	55	64	71	68	60	50	37	27	47.5
Mean, 1850 to 1870.	23	26	32	43	53	65	71	69	62	50	36	25	46.4
Mean, 1871 to 1891.	24.5	27.7	34.8	46.1	56.3	66.4	71.9	71.0	63.8	52.3	38.6	29.9	48.7
Mean, 1830 to 1891.	24.0	26.2	33.8	45.2	54.9	65.3	71.5	69.5	62.1	50.7	37.2	27.2	47.5

* Interpolated.

TABLE XX.—*Five coldest and warmest months at Chicago.*

COLDEST MONTHS.

January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		December.	
Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.	Year.	Temper-ature.
	°		°		°		°		°		°		°		°		°		°		°		°
1834	13	1832	15	1836	26	1837	38	1837	48	1836	59	1836	66	1835	65	1835	54	1833	46	1838	25	1831	15
1856	13	1835	14	1843	16	1838	40	1838	50	1842	59	1837	66	1836	62	1836	57	1843	44	1839	31	1856	18
1857	11	1838	11	1856	27	1852	39	1849	50	1862	57	1861	66	1837	65	1839	54	1863	40	1842	30	1859	16
1883	16	1843	13	1864	27	1857	35	1857	50	1863	59	1863	66	1842	65	1840	56	1864	43	1857	30	1864	18
1888	15	1875	15	1866	26	1864	39	1861	49	1864	61	1865	63	1856	65	1841	57	1869	43	1880	31	1872	19
WARMEST MONTHS.																							
1845	35	1834	35	1838	42	1830	53	1833	60	1867	72	1846	78	1846	75	1844	69	1830	57	1830	45	1874	34
1846	39	1877	36	1842	45	1839	53	1846	62	1873	70	1866	77	1867	74	1870	69	1839	59	1846	43	1875	37
1863	34	1878	36	1846	42	1842	52	1870	62	1874	70	1868	81	1876	74	1881	70	1879	60	1849	45	1877	43
1876	33	1880	35	1868	42	1844	55	1880	64	1880	70	1870	77	1878	74	1884	69	1882	57	1867	44	1881	37
1880	40	1882	38	1878	44	1878	52	1881	61	1890	70	1887	76	1881	75	1891	69	1886	57	1878	43	1891	35
COLDEST MONTHS.																							
1857	11	1838	11	1843	16	1857	35	1837	48	1862	57	1865	63	1836	62	1835	54	1863	40	1838	25	1831	15
SIGNAL SERVICE.																							
1888	15	1875	15	1872	28	1874	39	1882	52	1889	62	1891	67	1890	68	1888	60	1887	47	1880	31	1872	19
WARMEST MONTHS.																							
1880	40	1882	38	1842	45	1844	55	1880	64	1867	72	1868	81	1881	75	1881	70	1879	60	1849	45	1877	43
SIGNAL SERVICE.																							
1880	40	1882	38	1878	44	1878	52	1880	64	*1890	70	1878	75	1881	75	†1891	69	1879	60	1878	43	1877	43

*June, 1874, 70.5°, not as hot.

†September, 1881, 69.5°, not as hot.

In Table XX are given the 5 coldest and warmest months in the series, also the coldest and warmest for the whole series and for the Weather Service. It will be noted that the Auditorium has four of the values in the last two sets.

Table XXI contains a summary of Table XIX by seasons.

TABLE XXI.—*Mean temperature of Chicago by seasons.*

Year.	Winter.	Spring.	Summer.	Autumn.	Mean.
	°	°	°	°	°
1830 and 1831	21.3	45.7	70.3	47.3	46.2
1832	18.0	47.0	70.0	52.3	46.8
1833	30.2	48.0	68.8	49.8	49.2
1834	27.4	46.2	69.5	48.9	48.0
1835	23.9	43.0	65.1	45.5	44.4
1836	23.0	40.7	62.3	45.9	43.0
1837	24.1	38.0	64.0	49.7	44.0
1838	20.7	44.0	69.7	43.7	44.5
1839	25.3	47.3	66.7	48.0	46.8
1840	25.3	47.0	66.7	46.7	46.4
1841	23.7	43.7	67.7	47.3	45.6
1842	26.7	49.7	63.7	47.7	47.0
1843	20.4	38.0	67.7	47.3	43.4
1844	28.3	50.8	68.5	50.2	49.4
1845	33.0	49.3	71.0	50.3	50.9
1846	31.0	51.0	72.3	54.0	52.1
1847	28.0	44.0	69.3	52.0	48.3
1848	31.0	46.7	68.7	49.7	49.0
1849	23.3	43.3	67.3	52.3	46.6
1850	28.0	42.0	70.4	51.7	48.0
1851	29.7	46.0	68.0	51.3	48.8
1852	25.7	42.7	69.0	51.0	47.1
1853	28.9	44.7	67.7	50.4	47.9
1854	26.0	45.3	70.7	53.3	48.8
1855	24.0	45.0	66.6	48.3	46.0
1856	17.3	40.7	68.0	47.7	43.4
1857	19.9	37.6	67.8	47.2	43.1
1858	27.8	43.7	70.4	49.3	47.8
1859	28.0	44.7	69.0	47.0	47.2
1860	20.2	45.1	66.7	45.8	44.4
1861	23.9	41.3	66.0	47.8	44.8
1862	22.5	42.3	65.3	49.8	45.0
1863	28.1	42.2	63.5	43.4	44.3
1864	22.0	40.6	65.5	44.6	43.2
1865	20.3	42.0	64.7	49.4	44.1
1866	18.6	40.5	71.8	51.8	45.7
1867	25.5	42.2	73.3	55.7	49.2
1868	23.8	47.0	72.8	50.0	48.4
1869	27.7	42.6	69.2	47.3	46.7
1870	27.3	47.8	72.9	55.4	50.8
1871	29.7	49.7	70.8	50.2	50.1
1872	22.8	43.8	71.1	48.5	46.6
1873	21.2	43.7	71.1	48.4	46.1
1874	30.4	44.8	72.4	53.2	50.2
1875	22.0	43.3	66.8	48.5	45.2
1876	33.9	46.5	71.5	49.7	50.4
1877	26.1	43.9	70.1	53.6	48.4
1878	36.6	50.7	71.3	53.7	53.1
1879	24.2	47.8	70.1	54.3	49.1
1880	35.0	50.2	71.6	48.2	51.2
1881	22.4	44.9	70.3	55.1	48.2
1882	34.5	45.3	67.8	54.4	50.5
1883	21.8	43.0	67.8	51.3	46.0
1884	25.7	45.1	67.7	55.0	48.4
1885	21.2	42.7	69.1	52.3	46.3
1886	26.9	47.7	69.9	53.6	49.5
1887	23.1	46.2	70.0	49.3	47.2
1888	22.1	42.8	69.8	50.2	46.2
1889	27.0	47.7	67.8	50.3	48.2
1890	34.6	42.8	70.0	51.2	49.6
1891	29.8	43.7	67.2	51.8	48.1
Mean, 1831-1850	25.6	45.3	68.0	49.0	47.0
Mean, 1851-1870	24.4	43.2	68.4	49.3	46.3
Mean, 1871-1891	27.2	45.5	69.7	51.6	48.5
Mean, 1831-1891	25.8	44.6	68.7	50.0	47.3

The means of the annual temperatures observed by the Weather Service are here given in lustra, or periods of 5 years: 1871–1875, 47.8°; 1876–1880, 50.2°; 1881–1885, 48.0°; 1886–1890, 48.2°.

Table XXII shows the mean temperature for each five days from the beginning, or the mean by pentads.

TABLE XXII.—*Mean temperature of Chicago by pentads.*

(Each figure in this table is the mean of five days' observations, or of fifteen observations of temperature up to July, 1888.)

Year.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12	13.	14.	15.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1870 ..	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1871 ..	30	28	42	26	25	36	31	27	24	34	40	35	39	46	45
1872 ..	31	29	30	29	14	8	14	18	24	27	35	34	24	27	28
1873 ..	26	24	34	17	22	9	20	28	27	34	10	25	21	39	39
1874 ..	37	30	16	32	26	33	25	28	38	35	29	34	41	30	32
1875 ..	17	10	14	13	27	29	16	6	9	12	27	17	21	30	34
1876 ..	41	33	26	36	30	32	18	36	43	30	30	40	43	43	32
1877 ..	14	18	14	23	16	37	42	37	36	34	38	34	25	24	27
1878 ..	24	26	35	38	33	31	30	37	32	38	39	40	46	51	45
1879 ..	—5	14	26	18	33	37	29	33	22	28	29	25	39	52	32
1880 ..	42	45	36	43	39	37	23	30	38	37	39	47	46	33	27
1881 ..	22	12	18	22	25	19	18	33	25	21	22	29	28	34	36
1882 ..	27	37	30	22	26	30	36	40	45	40	27	25	41	32	33
1883 ..	19	18	36	19	9	27	10	10	28	29	30	31	32	28	35
1884 ..	4	14	25	20	17	34	29	31	24	35	24	25	16	28	38
1885 ..	24	36	22	4	12	9	29	20	3	4	15	35	36	29	29
1886 ..	37	16	19	19	14	26	7	32	41	28	34	23	29	33	37
1887 ..	4	4	23	18	32	24	16	30	24	31	29	29	31	39	33
1888 ..	21	22	3	5	16	21	30	7	20	33	32	27	23	32	27
1889 ..	34	29	28	29	29	25	30	16	19	23	7	27	38	32	47
1890 ..	39	31	35	24	17	38	40	27	35	40	25	24	15	32	27
1891 ..	28	30	27	30	29	35	21	31	33	33	36	17	24	30	33
Mean.	24.6	24.1	25·7	23·2	23·4	27·5	24·5	26·5	28·1	29·8	28·4	29·7	31·3	34·5	34·1

Year.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1870 ..	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1871 ..	41	38	39	50	59	43	51	47	52	46	46	55	62	64	70
1872 ..	24	31	34	38	49	46	44	53	54	50	64	51	57	55	58
1873 ..	38	29	39	51	40	44	41	37	45	48	50	49	52	62	61
1874 ..	46	36	34	31	36	43	40	40	41	43	63	58	50	62	73
1875 ..	20	38	50	45	54	42	31	37	46	44	56	50	57	61	62
1876 ..	22	34	34	39	44	48	48	50	52	44	50	58	71	58	70
1877 ..	28	34	40	40	41	45	50	54	42	46	47	57	63	52	63
1878 ..	41	42	41	47	50	49	58	57	52	54	54	48	58	62	56
1879 ..	30	41	43	33	47	42	42	64	55	50	51	63	58	57	65
1880 ..	39	40	42	50	42	46	50	49	49	65	68	56	68	65	64
1881 ..	33	32	30	26	35	37	43	54	53	47	64	68	55	59	73
1882 ..	39	39	43	52	46	36	50	43	48	49	57	44	57	51	53
1883 ..	26	32	37	40	44	55	47	42	45	47	52	48	59	52	55
1884 ..	38	46	42	40	37	48	41	44	56	55	54	54	60	64	51
1885 ..	16	32	38	41	43	38	47	55	47	47	42	56	56	58	56
1886 ..	45	41	34	31	44	52	57	58	54	57	53	56	54	62	61
1887 ..	29	32	25	40	52	56	42	45	50	59	56	59	60	65	58
1888 ..	37	24	36	44	43	44	43	41	57	50	53	44	48	61	59
1889 ..	38	43	36	40	47	43	56	50	47	50	76	52	66	51	49
1890 ..	39	39	30	42	45	46	42	51	48	47	45	49	49	63	67
1891 ..	35	35	40	34	37	46	54	54	58	46	56	58	55	51	52
Mean.	33·5	36·0	37·4	40·7	44·5	45·2	46·5	48.8	50·5	49·7	55·1	54·0	57·9	58·7	60.8

TABLE XXII.—*Mean temperature of Chicago by pentads*—Continued.

Year.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.	45.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1870 ..	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1871 ..	75	68	67	66	66	66	72	77	75	72	66	70	75	70	73
1872 ..	58	66	68	72	69	78	77	72	76	72	68	72	69	77	71
1873 ..	64	66	65	74	77	72	69	64	71	74	72	74	72	71	72
1874 ..	62	67	62	73	80	79	74	79	73	76	73	73	71	69	77
1875 ..	67	59	59	58	71	66	69	67	70	68	71	69	63	70	71
1876 ..	66	68	68	61	70	73	70	82	68	77	68	73	72	75	76
1877 ..	72	63	62	64	65	71	73	75	72	73	70	76	74	72	70
1878 ..	66	58	60	67	62	75	67	76	75	83	74	73	77	77	74
1879 ..	57	60	67	58	74	71	74	75	81	75	75	73	79	72	71
1880 ..	63	66	75	64	76	72	69	75	81	73	67	71	70	72	71
1881 ..	57	54	70	73	56	68	69	76	71	71	69	68	78	77	76
1882 ..	52	65	70	65	68	68	64	67	68	69	70	74	71	71	66
1883 ..	58	66	59	72	66	59	75	67	70	71	73	70	67	65	68
1884 ..	64	64	57	67	74	62	70	66	68	67	73	71	72	62	67
1885 ..	62	60	71	69	63	68	66	76	67	71	78	75	73	71	72
1886 ..	62	71	68	67	67	65	72	74	69	66	70	76	70	71	77
1887 ..	60	62	65	78	64	69	77	76	78	80	70	75	78	75	74
1888 ..	56	66	68	75	76	61	74	72	69	71	71	75	78	71	64
1889 ..	49	58	64	65	62	68	71	76	70	69	67	72	68	67	71
1890 ..	66	64	64	69	73	81	73	73	73	71	69	73	79	73	66
1891 ..	41	56	69	68	70	72	64	62	73	67	71	65	66	75	73
Mean.	60.8	63.3	65.6	67.9	69.0	69.7	70.9	72.7	72.0	72.0	70.7	72.3	72.5	71.6	71.4

Year.	46.	47.	48.	49.	50.	51.	52.	53.	54.	55.	56.	57.	58.	59.	60.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1870 ..	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1871 ..	73	71	69	64	70	63	59	58	55	55	58	60	53	54	52
1872 ..	71	78	73	63	76	68	60	63	60	52	58	48	44	53	46
1873 ..	68	75	72	73	65	68	59	56	62	57	50	57	60	45	44
1874 ..	73	74	71	71	69	76	65	62	65	55	54	50	51	55	60
1875 ..	69	60	73	78	72	64	60	49	58	53	53	42	44	52	49
1876 ..	74	74	68	70	64	63	59	65	61	50	49	44	42	56	46
1877 ..	68	70	73	69	65	66	69	62	70	69	54	50	64	51	56
1878 ..	72	74	80	72	72	64	64	66	60	68	58	57	59	48	43
1879 ..	65	76	70	75	64	60	59	57	56	72	71	70	68	53	46
1880 ..	73	74	79	74	69	60	61	62	63	57	53	62	52	42	45
1881 ..	71	69	75	78	78	67	62	66	74	65	58	61	55	51	55
1882 ..	72	76	72	69	67	67	71	62	58	64	67	58	59	49	51
1883 ..	70	73	66	70	62	58	67	61	58	52	53	62	50	50	46
1884 ..	76	73	66	67	76	72	67	62	67	69	71	56	57	56	43
1885 ..	67	70	61	62	58	63	66	68	65	66	46	55	55	46	52
1886 ..	71	74	76	66	76	67	63	62	71	50	59	69	57	58	49
1887 ..	68	67	60	69	71	63	62	64	53	58	56	54	49	43	36
1888 ..	72	67	69	66	65	68	58	59	56	50	52	48	48	43	51
1889 ..	64	72	76	77	69	69	65	52	57	57	50	56	49	48	44
1890 ..	67	68	67	64	73	63	56	57	54	56	60	60	53	48	46
1891 ..	73	68	61	64	59	64	71	77	77	66	57	53	48	45	52
Mean.	70.3	71.6	70.3	69.6	68.6	65.4	63.0	61.4	61.9	59.1	56.5	56.0	53.2	49.8	48.2

TABLE XXII.—*Mean temperature of Chicago bg pentads*—Continued.

Year.	61.	62.	63.	64.	65.	66.	67.	68.	69.	70.	71.	72.	73.
	°	°	°	°	°	°	°	°	°	°	°	°	°
1870	......	49	47	45	38	39	46	42	37	34	25	5	28
1871	42	45	42	38	34	23	22	18	24	26	10	24	23
1872	49	42	44	30	22	34	15	29	22	29	14	4	22
1873	32	40	41	32	29	34	28	33	36	31	30	33	26
1874	44	55	52	44	32	34	24	40	32	34	34	33	27
1875	44	42	44	38	40	34	32	43	36	30	29	40	43
1876	60	44	43	44	42	32	23	27	14	23	19	19	20
1877	48	37	40	48	42	44	26	35	37	46	54	48	39
1878	40	44	45	45	45	39	39	35	33	29	20	8	15
1879	40	35	56	52	33	36	40	44	35	26	21	18	34
1880	45	48	44	29	16	22	27	26	15	35	30	28	1
1881	55	44	45	38	34	29	45	38	33	40	43	38	30
1882	51	47	55	36	40	35	33	26	14	20	32	34	28
1883	48	50	48	25	46	43	38	38	39	30	12	29	29
1884	47	42	48	47	40	30	32	45	35	26	9	4	2
1885	44	46	46	38	44	37	40	28	21	25	33	38	40
1880	52	46	39	39	37	32	27	19	41	28	25	25	14
1887	42	48	41	42	29	38	24	37	36	30	30	18	10
1888	54	52	42	44	32	38	37	35	38	30	25	38	28
1889	46	39	45	39	43	36	25	38	45	42	42	43	35
1890	38	42	41	46	46	39	36	23	30	32	38	28	33
1891	49	41	46	36	28	32	19	36	31	41	35	35	35
Mean	46.1	44.5	45.2	39.8	36.0	34.5	30.8	33.4	31.1	31.2	27.7	26.8	25.5

Table XXIII contains the normal, or the mean of all the daily temperatures from the beginning, that is, the mean of the mean

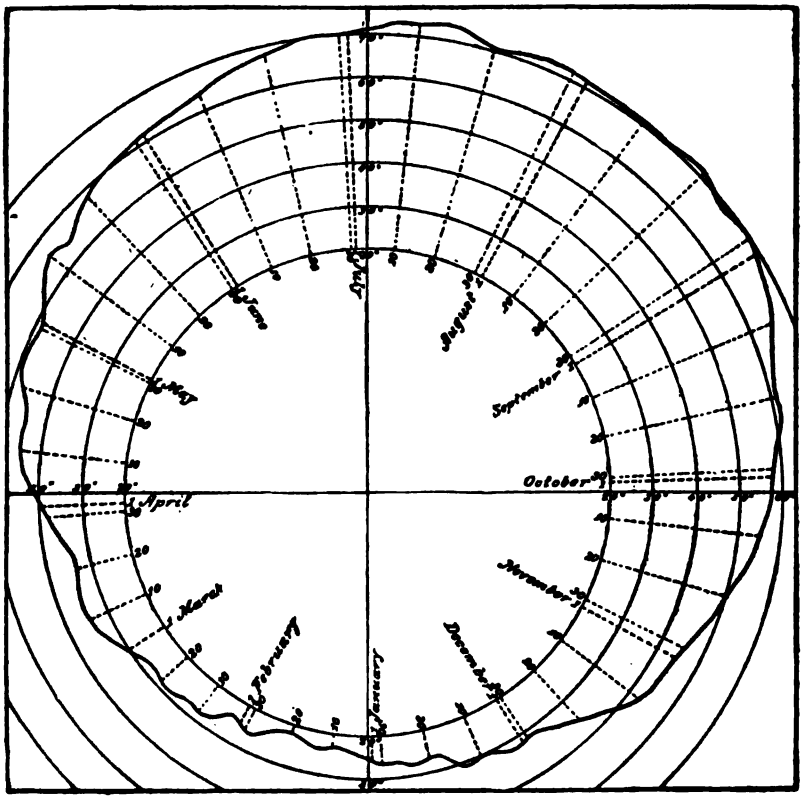


FIG. 11.—*Daily normal temperature.*

daily temperature for January 1 for 20 years is taken as the first mean, for January 2, as the second, and so on. The mean of successive 5 days has been projected in Fig. 11. The mean for the year is 48.6°, and this comes on April 23 and October 24, that is, during 181 days the temperature is below the mean, and for 184 it is above. The highest temperature occurs on July 14, and the lowest January 21, so that for 174 days the temperature is rising and during 191 it is falling. Perhaps the most interesting point in Fig. 11 is the well marked "cold spell" in May. This has been almost universally observed in the northern hemisphere toward the end of the second week, and has received the term "ice saint's days," "May cold spell," etc. The lowest point of the "cold spell" occurs in this record on May 13 and 14. The rise or fall of temperature from the first to the last day in each month is as follows:

February, +5.4°; March, +7.4°; April, +9.0°; May, +12.8°; June, +8.6°; August, —3.2°; September, —11.0°; October, —13.4°; November, —14.2°; December, —4.2°. This shows that the rise in temperature is fastest in May and is a little less than one degree in two days. The fall is about the same in October and November, or about one degree in two days.

TABLE XXIII.—*Daily normal temperatures, Chicago.*

Date.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	°	°	°	°	°	°	°	°	°	°	°	°
1	26	23	33	39	47	61	71	73	69	58	45	32
2	23	24	32	39	49	63	71	72	69	59	44	33
3	24	26	29	42	51	63	73	72	69	58	44	34
4	24	24	29	41	51	63	70	72	69	56	45	33
5	25	24	32	43	52	63	72	71	69	55	44	32
6	24	27	35	44	52	62	73	71	70	54	44	32
7	24	29	32	43	53	62	74	72	68	57	46	30
8	24	28	35	45	58	64	75	72	67	57	45	30
9	22	26	35	46	56	62	73	71	66	58	45	29
10	22	31	36	45	56	63	71	70	64	55	44	32
11	25	30	36	44	56	65	72	72	64	55	44	32
12	28	28	34	45	55	65	74	72	65	55	42	33
13	24	26	34	46	52	65	72	71	62	54	40	33
14	22	25	34	48	53	66	74	70	62	53	39	29
15	25	29	34	44	53	68	75	70	64	54	38	28
16	23	30	33	42	56	66	74	70	62	52	39	28
17	22	30	34	45	58	67	72	70	62	52	39	26
18	23	30	35	49	58	69	70	72	62	49	37	26
19	23	28	34	46	61	68	70	73	61	51	35	28
20	23	27	32	48	59	69	70	72	59	51	36	30
21	22	28	32	48	57	66	70	72	61	51	36	28
22	22	28	34	50	58	68	71	70	61	50	36	29
23	21	26	35	49	58	71	71	69	62	48	34	28
24	23	30	35	47	62	71	72	69	63	48	32	28
25	25	30	37	49	59	69	73	70	61	49	34	28
26	28	29	39	51	61	70	72	70	59	47	35	28
27	28	28	36	51	61	71	73	71	59	46	33	25
28	24	31	36	50	61	69	73	71	58	49	29	25
29	26	......	35	48	62	69	72	70	59	47	27	28
30	28	......	37	48	61	71	74	70	58	45	30	29
31	25	......	40	......	60	......	73	70	......	44	......	29
Mean	24.1	27.7	34.3	45.8	56.3	66.3	72.3	71.0	63.5	52.2	38.7	29.5

ACCUMULATED TEMPERATURE.

If we subtract the temperature for each succeeding day and make the algebraic sum with the sum for the preceding days, we shall have what may be called the increase or accumulated change in temperature. Table XXIV exhibits the normal accumulated temperature for the middle and last days of each month.

TABLE XXIV.—*Normal accumulated temperatures.*

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
15th	−1	3	8	18	27	42	49	44	38	28	12	2
Last	−1	5	14	22	34	45	47	44	32	18	4	3

On making a similar summation for any year we can tell, by comparing with this table, whether there has been an excess or deficiency in the temperature.

HIGHEST AND LOWEST TEMPERATURES.

TABLE XXV.—*Maximum and minimum temperatures for Chicago.*

MAXIMUM.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1872	......	......	......	......	......	98	97	93	93	81	59	46
1873	51	53	60	83	87	92	93	92	88	75	59	60
1874	60	56	64	67	89	95	99	98	89	78	72	52
1875	44	45	73	72	75	87	88	86	87	73	57	68
1876	65	63	69	70	87	88	93	92	78	73	66	45
1877	56	58	65	78	86	87	91	89	86	80	58	67
1878	49	55	68	75	78	85	97	91	87	79	57	46
1879	49	51	71	80	87	87	93	91	83	84	69	62
1880	61	63	60	80	85	91	95	93	85	78	65	50
1881	41	51	48	77	87	89	93	98	94	77	64	59
1882	58	62	63	76	76	88	90	87	87	77	72	45
1883	40	57	62	78	80	84	91	89	84	78	62	57
1884	49	53	59	77	78	86	89	91	89	83	64	61
1885	50	47	58	76	80	88	94	85	81	69	66	50
1886	48	56	70	81	82	87	94	92	86	79	69	60
1887	52	58	68	82	86	96	100	98	92	82	67	53
1888	44	47	64	83	81	90	94	91	88	76	75	53
1889	55	48	68	73	88	86	90	88	84	79	57	64
1890	62	59	56	75	86	92	93	96	88	73	67	53
1891	54	58	57	75	81	88	87	96	91	86	60	57

MINIMUM.

1872	......	......	......	......	......	51	52	47	37	27	−2	−23
1873	−16	−18	−12	25	35	44	50	53	41	23	8	13
1874	−6	9	17	22	38	46	60	58	44	30	zero	1
1875	−20	−13	9	17	27	40	56	52	40	30	zero	−1
1876	4	−3	10	32	35	47	57	54	37	28	14	−14
1877	−4	21	5	27	33	45	57	55	44	35	14	22
1878	−1	17	25	36	38	50	59	57	43	27	31	−9
1879	−18	−6	16	17	39	43	60	52	39	28	16	−2
1880	19	12	19	27	37	52	57	53	40	28	1	−15
1881	−13	8	11	17	37	46	57	58	49	41	14	13
1882	1	10	22	25	34	42	55	51	42	40	21	−7
1883	−17	−9	10	28	36	48	51	54	42	38	10	zero
1884	−18	−3	−1	31	40	47	54	51	51	28	5	11
1885	−13	−14	4	27	34	42	53	55	47	36	28	−3
1886	−14	−6	15	23	40	49	55	53	42	32	16	−10
1887	−15	−7	9	19	42	48	61	49	38	14	−1	−5
1888	−17	−18	−1	30	32	43	56	51	36	32	20	15
1889	zero	−11	20	29	36	42	54	54	35	35	12	15
1890	−5	3	zero	28	34	52	56	51	39	28	27	8
1891	10	−8	7	23	35	44	55	49	48	33	3	9

TABLE XXVI.—*Number of times maximum below 82°, maximum above 90°, and minimum below 82°, Chicago.*

Year.	January.		February.		March.		April.		May.	June.	July.	August.	September.	October.		November.		December.	
	Max. below 32°.	Min. below 32°.	Max. below 32°.	Min. below 32°.	Max. below 32°.	Min. below 32°.	Max. below 32°.	Min. below 32°.	Min. below 32°.	Max. above 90°.	Max. above 90°.	Max. above 90°.	Max. above 90°.	Max. below 32°.	Min. below 32°.	Max. below 32°.	Min. below 32°.	Max. below 32°.	Min. below 32°.
1873..........	18	30	7	28	5	24	0	11	0	2	1	2	0	1	5	6	18	8	19
1874..........	8	23	11	23	6	18	4	10	0	3	7	5	0	0	1	3	14	22	25
1875..........	20	30	20	28	12	21	2	8	1	0	0	0	0	0	1	1	13	3	18
1876..........	6	23	7	17	8	20	0	0	0	0	4	1	0	0	0	2	11	22	30
1877..........	15	28	0	12	13	28	0	2	0	0	1	0	0	0	0	2	11	1	7
1878..........	4	18	1	11	0	2	0	0	0	0	2	1	0	0	3	0	1	15	25
1879..........	17	27	11	26	2	11	1	3	0	0	3	1	0	0	1	1	13	7	22
1880..........	0	12	6	17	1	14	0	3	0	1	4	1	0	0	2	10	20	11	27
1881..........	21	31	14	27	3	28	1	8	0	0	5	5	2	0	0	1	10	2	11
1882..........	9	28	2	14	0	13	0	3	0	0	0	0	0	0	0	0	10	12	16
1883..........	20	31	13	26	6	26	0	2	0	0	1	0	0	0	0	2	12	8	22
1884..........	18	29	8	25	9	15	0	1	0	0	0	1	0	0	1	2	9	10	20
1885..........	18	28	18	26	7	25	0	5	0	0	3	0	0	0	0	0	4	7	20
1886..........	17	28	8	23	3	17	0	5	0	0	2	1	0	0	0	3	16	13	27
1887..........	19	30	11	28	6	27	0	6	0	2	5	2	1	1	9	2	19	11	25
1888..........	23	30	10	26	11	27	0	6	0	0	3	1	0	0	1	1	7	6	24
1889..........	11	28	16	27	2	11	0	1	0	0	0	0	0	0	0	3	11	1	7
1890..........	9	21	6	20	9	24	0	3	0	1	4	2	0	0	2	0	7	10	25
1891..........	9	25	9	23	10	24	2	5	0	0	0	3	1	0	0	7	17	4	16
Mean...	13·8	26·3	9·4	22·5	5·9	19·7	0·5	4·3	0·05	0·5	2·4	1·4	0·2	0·1	1·4	2·4	11·7	9·1	20·3

Table XXV gives the highest and lowest temperatures observed in each month during which maximum and minimum thermometers were in use. The highest temperature during the 20 years was 99.6°, on July 17, 1887, and the lowest was —23°, December 24, 1872.

Table XXVI shows the number of times during each month that the maximum was below 32° or above 90°, and the minimum below 32°.

Table XXVII gives the dates on which the minimum temperature was —15° or below, at the Weather Service thermometer. We see that this temperature was reached but 16 times in the 20 years, or, we may say, that on the average we can expect such temperature once a year.

TABLE XXVII.—*Dates on which the minimum temperature was* —15° *or below at Chicago from June* 12, 1872, *to December* 31, 1890.

Year.	Date.	Remarks.	Year.	Date.	Remarks.
1872..	Dec. 22, 23, and 24.		1882..	None	Lowest, —7°, Dec. 8.
1873..	Jan. 29; Feb. 23...		1883..	January 21 and 22.	
1874..	None	Lowest, —6°, Jan. 15.	1884..	January 5	
1875..	January 9.........		1885..	None	Lowest, —14°, Feb. 10 and 11.
1876..	None	Lowest, —14°, Dec. 9.			
1877..	...do	Lowest, —4°, Jan. 23.	1886..	...do....	Lowest, —14°, Jan. 23.
1878..	...do	Lowest, —9°, Dec 24.	1887..	January 3 and 7 ..	
1879..	January 2 and 3...		1888..	Jan. 16; Feb. 9...	
1880..	December 29		1889..	None	Lowest, —11°, Feb. 23.
1881..	None	Lowest; —13°, Jan. 14.	1890..	...do	Lowest, —5°, Jan. 22.

Table XXVIII gives the dates on which the maximum temperature was 90° or over. There are 121 cases in the 19 years, or about 6 each year. 1875 had no case; 1882 and 1884, one each; and 1877 and 1889, two each.

TABLE XXVIII.—*Dates on which the maximum temperature was* 90° *or above at Chicago from June* 12, 1872, *to December* 31, 1890.

Year.	Date.	Year.	Date.	Year.	Date.	Year.	Date.
1872...........	June 18	1874..........	July 6	1879..........	Aug. 2	1886..........	July 28
1872...........	June 19	1874..........	July 7	1880..........	June 11	1886..........	Aug. 21
1872...........	June 20	1874..........	July 14	1880..........	July 10	1887..........	June 16
1872...........	June 27	1874..........	July 19	1880..........	July 11	1887..........	June 17
1872...........	June 28	1874..........	July 25	1880..........	July 12	1887..........	July 12
1872...........	June 30	1874..........	Aug. 11	1880..........	July 13	1887..........	July 15
1872...........	July 1	1874..........	Aug. 17	1880..........	Aug. 18	1887..........	July 16
1872...........	July 2	1874..........	Aug. 19	1881..........	July 5	1887..........	July 17
1872...........	July 9	1874..........	Aug. 20	1881..........	July 7	1887..........	July 27
1872...........	July 15	1874..........	Aug. 21	1881..........	July 8	1887..........	Aug. 3
1872...........	Aug. 6	1875*.........	None.	1881..........	July 9	1887..........	Aug. 9
1872...........	Aug. 7	1876..........	July 6	1881..........	July 12	1887.........	Aug. 10
1872...........	Aug. 8	1876..........	July 7	1881..........	Aug. 3	1887..........	Sept. 6
1872...........	Aug. 9	1876..........	July 8	1881..........	Aug. 4	1888..........	June 20
1872...........	Aug. 20	1876..........	July 9	1881..........	Aug. 11	1888..........	July 3
1872...........	Aug. 21	1876..........	July 17	1881..........	Aug. 12	1888..........	July 6
1872...........	Sept. 5	1876..........	July 19	1881..........	Aug. 30	1888..........	July 30
1872...........	Sept. 6	1876..........	Aug. 23	1881..........	Sept. 5	1888..........	July 31
1873...........	June 19	1877..........	July 8	1881..........	Sept. 6	1888..........	Aug. 3
1873...........	June 23	1877..........	July 15	1882..........	July 27	1889..........	July 8
1873...........	July 16	1878..........	July 16	1883..........	July 2	1889..........	July 9
1873...........	July 17	1878..........	July 17	1883..........	July 3	1890..........	June 28
1873...........	Aug. 22	1878..........	July 20	1883..........	July 4	1890..........	June 29
1873...........	Aug. 24	1878..........	Aug. 8	1883..........	July 22	1890..........	June 30
1873...........	Aug. 31	1879..........	July 3	1884..........	Aug. 19	1890..........	July 7
1874...........	June 8	1879..........	July 10	1885..........	July 8	1890..........	July 14
1874...........	June 22	1879..........	July 11	1885..........	July 19	1890..........	July 29
1874...........	June 23	1879..........	July 14	1885..........	July 20	1890..........	July 30
1874...........	June 27	1879..........	July 15	1885..........	July 28	1890..........	Aug. 2
1874...........	June 28	1879..........	July 16	1886..........	July 6	1890..........	Aug. 8
1874...........	July 3			1886..........	July 25		

*Highest, 88°, July 15.

COLD WAVES.

A cold wave may be considered as one in which the temperature fall is 18° or more in 24 hours, and the point reached is 34° or below. Table XXIX exhibits all the cases of such cold waves in the 21 years here included. There were 179 in all, or less than 9 per year. The distribution by months was as follows:

January, 58; February, 43; March, 18; April, 6; October, 2; November, 20; December, 32. The latest ever noted was on April 22, 1872, and the earliest, October 10 of the same year.

TABLE XXIX.—*Dates on which the 7 or 8 a. m. temperature had fallen 18° or more in 24 hours, and to 34° or below.*

Year.	Date.	Year.	Date.	Year.	Date.	Year.	Date.
1870	Nov. 14	1875	Nov. 24	1882	Nov. 24	1887	Jan. 18
1871	Jan. 6	1875	Nov. 29	1882	Dec. 7	1887	Jan. 21
1871	Feb. 9	1875	Dec. 17	1883	Jan. 14	1887	Jan. 26
1871	Feb. 18	1876	Jan. 6	1883	Jan. 18	1887	Feb. 4
1871	Dec. 4	1876	Jan. 10	1883	Jan. 20	1887	Feb. 9
1871	Dec. 8	1876	Jan. 19	1883	Jan. 31	1887	Feb. 12
1871	Dec. 20	1876	Jan. 29	1883	Feb. 1	1887	Feb. 19
1871	Dec. 27	1876	Feb. 2	1883	Feb. 17	1887	Feb. 27
1872	Jan. 23	1876	Feb. 4	1883	Feb. 21	1887	Apr. 4
1872	Feb. 14	1876	Feb. 14	1883	Mar. 7	1887	Nov. 20
1872	Feb. 25	1876	Feb. 22	1883	Mar. 19	1887	Nov. 28
1872	Mar. 15	1876	Dec. 9	1883	Dec. 8	1887	Dec. 5
1872	Mar. 20	1876	Dec. 15	1883	Dec. 15	1887	Dec. 21
1872	Apr. 22	1877	Jan. 8	1883	Dec. 27	1887	Dec. 28
1872	Oct. 10	1877	Jan. 20	1884	Jan. 3	1888	Jan. 11
1872	Nov. 14	1877	Mar. 4	1884	Jan. 20	1888	Jan. 18
1872	Nov. 27	1877	Apr. 2	1884	Jan. 24	1888	Jan. 26
1872	Dec. 9	1878	Jan. 5	1884	Jan. 31	1888	Feb. 6
1872	Dec. 15	1878	Jan. 23	1884	Feb. 14	1888	Feb. 8
1873	Jan. 4	1878	Dec. 23	1884	Feb. 20	1888	Feb. 15
1873	Jan. 17	1879	Jan. 2	1884	Feb. 28	1888	Feb. 20
1873	Feb. 19	1879	Nov. 29	1884	Mar. 12	1888	Feb. 26
1873	Feb. 21	1879	Dec. 11	1884	Nov. 24	1888	Mar. 3
1873	Mar. 3	1880	Jan. 10	1884	Nov. 26	1888	Mar. 11
1873	Mar. 16	1880	Jan. 12	1884	Dec. 31	1888	Mar. 20
1873	Mar. 20	1880	Jan. 31	1885	Jan. 1	1888	Mar. 22
1873	Oct. 28	1880	Feb. 29	1885	Jan. 13	1888	Nov. 16
1873	Dec. 4	1880	Mar. 8	1885	Feb. 10	1889	Jan. 10
1874	Jan. 5	1880	Apr. 11	1885	Feb. 16	1889	Jan. 17
1874	Feb. 9	1880	Nov. 21	1885	Apr. 8	1889	Jan. 21
1874	Mar. 4	1880	Dec. 28	1885	Nov. 13	1889	Feb. 5
1874	Mar. 8	1881	Jan. 7	1885	Dec. 11	1889	Feb. 12
1874	Nov. 18	1881	Jan. 10	1885	Dec. 15	1889	Feb. 23
1874	Nov. 24	1881	Jan. 14	1886	Jan. 10	1889	Dec. 25
1874	Dec. 14	1881	Feb. 28	1886	Jan. 17	1889	Dec. 30
1874	Dec. 29	1881	Dec. 1	1886	Jan. 23	1890	Jan. 6
1875	Jan. 9	1881	Dec. 14	1886	Feb. 20	1890	Jan. 13
1875	Jan. 14	1882	Jan. 9	1886	Feb. 26	1890	Jan. 16
1875	Jan. 22	1882	Jan. 14	1886	Nov. 18	1890	Jan. 20
1875	Jan. 25	1882	Jan. 17	1886	Nov. 24	1890	Jan. 24
1875	Feb. 3	1882	Jan. 22	1886	Dec. 2	1890	Feb. 5
1875	Feb. 4	1882	Jan. 29	1886	Dec. 15	1890	Feb. 8
1875	Mar. 16	1882	Feb. 8	1886	Dec. 27	1890	Mar. 1
1875	Apr. 16	1882	Feb. 17	1887	Jan. 1	1890	Nov. 10
1875	Nov. 21	1882	Feb. 22	1887	Jan. 10		

VARIABILITY OF TEMPERATURE.

If we subtract the mean temperature for each day from that for the preceding day and add the differences without regard to signs, and then divide the sum by the number of days in the month, we shall obtain what has been called the "variability" of temperature. This, for each month of 1888–1891, is as follows:

January, 7.1°; February, 8.4°; March, 5.7°; April, 6.7°; May, 6.3°; June, 5.0°; July, 4.4°; August, 3.9°; September, 4.4°; October, 4.3°; November, 5.0°; December, 5.9°.

We see that the variability is much greater during the months of rising than falling temperature, in the ratio 6.5:4.7. This shows a rather mild and favorable condition during the autumn months for Chicago.

It is of interest to compare the variability at a number of stations widely distributed over this country. Table XXX gives these values.

TABLE XXX.—*Variability of temperature from* 1881 *to* 1887.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	°	°	°	°	°	°	°	°	°	°	°	°	°
Chicago	8.2	7.1	5.5	5.6	5.5	5.6	4.1	3.3	4.2	4.6	5.4	6.6	5.5
Assinaboine	7.2	6.5	4.7	4.7	4.1	4.0	3.3	3.1	3.8	5.0	4.7	6.5	4.8
Brownsville	6.8	5.2	4.4	3.0	1.9	1.3	1.0	1.4	1.9	2.6	4.7	5.7	3.3
Charleston	6.1	5.7	5.0	3.8	2.7	2.4	1.7	1.9	1.9	3.2	4.7	5.4	3.7
Cincinnati	8.0	7.8	6.7	4.8	4.2	3.5	2.5	2.8	3.5	4.4	6.2	6.4	5.1
Denver	9.2	6.5	6.1	5.1	4.6	3.4	3.5	3.0	4.3	5.5	6.1	7.6	5.4
Key West	2.9	2.3	2.4	1.7	1.3	1.3	1.2	1.3	1.3	1.2	1.8	2.8	1.8
New Orleans	6.2	4.7	3.9	3.1	1.9	1.5	1.6	1.5	1.6	2.4	4.3	5.6	3.2
Omaha	8.6	7.9	6.8	6.4	4.6	3.8	3.6	3.7	4.9	5.4	7.0	7.3	5.8
Saint Vincent	9.2	9.4	7.7	5.5	5.4	4.6	3.4	4.4	5.1	5.4	6.3	8.4	6.2
Salt Lake City	4.2	4.5	3.7	4.5	4.7	3.7	3.3	3.1	4.0	4.2	3.7	3.3	3.9
San Francisco	1.9	2.2	2.1	1.9	2.4	1.8	1.6	1.6	2.4	2.1	1.7	2.0	2.0
Tatoosh	2.5	2.2	1.7	1.5	1.6	1.3	1.2	1.7	1.4	1.5	1.9	2.3	1.7
Washington, D.C.	5.9	6.3	5.4	5.0	4.5	3.8	3.1	2.9	3.8	4.8	5.2	5.5	4.7

The variability is about the same for stations within two hundred miles, since this is dependent upon the storms and cold waves which pass over this region.

HOURLY TEMPERATURE.

Tables XXXI and XXXII give the hourly temperatures observed with a thermograph during 1890 and 1891; also hourly pressures given by a barograph. In Fig. 12 are given what are called "chrono-isotherms," or a delineation of the hourly temperatures according to the months of the year. The relation of the temperature march by months is shown still more strikingly in Fig. 13, in which the mean for each month has been subtracted from the temperature for each hour, and this departure has been charted with the months in combination. The times of sunrise and sunset are given in the dotted lines on the left and right.

TABLE XXXI.—*Mean hourly pressure and temperature for 1890, Chicago.*

PRESSURE (base number, 29.''+).

Months.	24.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Mean
January	·221	·215	·218	·218	·214	·218	·228	·236	·245	·259	·268	·269	·247	·229	·221	·224	·226	·233	·230	·229	·230	·232	·235	·233	·232
February	·167	·169	·167	·164	·166	·166	·167	·169	·175	·173	·170	·165	·145	·124	·122	·119	·122	·132	·139	·148	·150	·151	·154	·156	·153
March	·168	·165	·161	·157	·160	·161	·173	·185	·195	·197	·198	·192	·187	·177	·171	·165	·162	·164	·170	·174	·178	·178	·180	·173	·175
April	·210	·199	·199	·199	·201	·205	·218	·229	·233	·236	·235	·232	·221	·214	·203	·190	·187	·186	·186	·192	·201	·200	·199	·198	·207
May	·035	·033	·028	·026	·030	·039	·048	·054	·061	·058	·058	·057	·050	·042	·036	·029	·023	·025	·022	·025	·035	·036	·043	·042	·039
June	·108	·098	·100	·102	·106	·111	·117	·126	·130	·129	·130	·129	·122	·115	·104	·091	·084	·080	·080	·086	·090	·097	·098	·098	·105
July	·138	·137	·133	·133	·137	·145	·151	·161	·162	·163	·166	·166	·162	·152	·141	·136	·130	·125	·124	·125	·130	·137	·141	·145	·143
August	·183	·181	·180	·179	·181	·187	·199	·208	·210	·212	·215	·212	·206	·197	·187	·179	·175	·173	·174	·171	·180	·187	·189	·190	·190
September	·226	·225	·223	·224	·228	·233	·240	·249	·257	·262	·262	·257	·248	·236	·220	·215	·211	·211	·212	·210	·219	·225	·225	·227	·231
October	·053	·052	·048	·046	·048	·051	·056	·066	·068	·070	·065	·065	·054	·045	·041	·040	·040	·045	·053	·057	·062	·062	·059	·053	·054
November	·172	·166	·169	·165	·166	·164	·166	·174	·180	·184	·183	·181	·165	·158	·152	·154	·157	·162	·169	·170	·173	·172	·171	·167	·168
December	·194	·192	·199	·198	·193	·190	·199	·207	·205	·215	·202	·210	·191	·176	·167	·170	·172	·179	·185	·191	·191	·190	·188	·191	·191
Year	·156	·153	·152	·151	·152	·156	·164	·172	·177	·180	·179	·178	·166	·155	·147	·143	·141	·143	·145	·148	·153	·156	·157	·156	·157

TEMPERATURE.

	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	31·2	30·6	30·2	29·5	29·2	28·6	28·7	28·7	28·9	29·4	30·1	31·4	32·7	34·2	34·5	34·7	34·5	34·3	33·9	33·3	32·6	31·9	31·6	31·4	31·5
February	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
March	28·8	28·1	27·6	27·1	26·6	26·1	25·7	25·4	26·1	27·3	28·9	30·0	30·7	31·7	32·4	32·7	33·1	33·0	32·3	31·3	30·9	30·7	30·0	29·8	29·4
April	44·9	44·8	44·4	43·8	43·3	42·9	42·6	42·9	43·6	44·5	45·5	46·6	47·4	48·3	49·2	49·1	49·5	48·6	46·8	45·8	45·6	46·0	45·6	45·2	45·7
May	50·8	50·3	49·9	49·5	48·8	48·5	48·5	50·1	51·2	52·2	54·6	55·4	54·5	55·4	56·2	56·9	57·5	56·8	56·5	55·2	54·4	53·2	52·4	51·9	52·9
June	68·5	68·2	67·7	67·2	66·7	66·5	66·6	67·9	68·6	69·7	71·4	71·9	72·0	72·1	72·5	72·1	72·5	72·6	72·1	71·2	70·6	70·0	69·7	69·6	69·9
July	71·5	70·8	70·1	69·5	69·2	68·8	68·8	69·6	70·1	71·2	73·8	74·2	74·2	74·7	74·9	75·4	76·0	75·7	75·1	74·2	73·3	72·7	72·2	71·8	72·4
August	64·4	64·0	63·6	62·9	62·4	61·7	61·4	62·0	62·8	63·6	65·4	66·2	66·8	67·4	67·6	67·8	68·8	68·6	68·1	66·4	66·2	65·7	65·3	64·8	65·2
September	60·4	59·8	59·2	58·8	58·1	57·6	56·9	57·0	57·8	59·4	61·7	62·5	62·9	63·7	63·8	64·3	64·7	64·6	64·0	63·0	62·6	62·2	61·4	60·8	61·1
October	51·5	50·9	50·6	50·1	49·6	49·4	49·0	49·1	49·3	50·3	52·5	53·0	53·0	53·4	53·3	53·5	53·8	53·6	53·0	52·1	51·9	51·6	51·5	51·1	51·5
November	42·0	41·2	40·5	40·0	39·6	39·0	38·7	37·7	37·8	38·7	41·4	42·7	43·8	45·3	45·7	45·9	45·9	45·7	44·8	43·8	43·7	43·5	43·0	42·7	42·2
December	31·7	31·5	31·2	31·0	30·5	30·1	30·0	29·5	29·5	30·0	31·8	33·2	34·3	35·5	36·1	36·1	36·2	35·6	34·7	33·8	33·1	32·7	32·3	32·2	32·6
Year	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

TABLE XXXII.—*Mean hourly pressure and temperature for* 1891, *Chicago.*

PRESSURE (base number, 29.″+).

Months.	24.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Mean
January.........	.152	.153	.156	.153	.145	.145	.149	.156	.160	.164	.163	.153	.131	.117	.115	.122	.129	.136	.146	.157	.165	.166	.167	.165	.149
February	.089	.086	.090	.089	.089	.095	.103	.119	.122	.123	.129	.124	.109	.090	.079	.076	.075	.080	.094	.100	.110	.113	.116	.116	.101
March	.163	.161	.153	.144	.144	.147	.147	.150	.146	.145	.143	.142	.135	.121	.113	.108	.106	.115	.122	.124	.132	.136	.140	.142	.137
April............	.120	.116	.113	.113	.115	.123	.131	.140	.142	.144	.147	.144	.136	.127	.115	.115	.113	.107	.107	.111	.118	.129	.129	.128	.124
May.............	.220	.218	.219	.222	.226	.235	.249	.260	.263	.262	.265	.259	.248	.237	.225	.212	.205	.200	.197	.200	.205	.215	.216	.215	.228
June	.004	.060	.062	.062	.070	.078	.087	.094	.100	.100	.101	.098	.092	.077	.070	.060	.050	.042	.047	.050	.057	.066	.071	.070	.072
July	.147	.147	.145	.147	.153	.160	.171	.176	.181	.182	.184	.180	.176	.162	.155	.149	.144	.137	.136	.138	.139	.145	.145	.145	.156
August..........	.116	.113	.112	.115	.120	.127	.134	.140	.142	.145	.146	.139	.132	.120	.110	.103	.105	.104	.105	.106	.118	.123	.125	.125	.122
September	.243	.244	.243	.248	.250	.256	.266	.274	.277	.281	.280	.272	.262	.248	.234	.222	.216	.216	.217	.222	.232	.237	.239	.243	.247
October	.224	.224	.219	.218	.220	.223	.228	.234	.232	.235	.233	.228	.213	.200	.195	.192	.192	.197	.206	.215	.220	.223	.224	.221	.217
November	.177	.176	.175	.170	.165	.167	.168	.171	.180	.179	.176	.169	.156	.147	.142	.144	.150	.158	.169	.169	.171	.176	.179	.176	.167
December.......	.150	.148	.153	.153	.149	.150	.158	.162	.168	.174	.174	.161	.135	.118	.108	.113	.118	.121	.125	.129	.134	.136	.138	.140	.142
Year	.155	.154	.153	.153	.154	.159	.166	.173	.176	.178	.178	.172	.160	.147	.138	.135	.134	.134	.139	.143	.150	.155	.157	.157	.155

TEMPERATURE.

Months.	24.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Mean
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January.........	29.8	29.6	29.4	29.3	29.0	28.7	28.5	28.4	28.5	28.9	29.7	30.2	30.8	31.4	31.7	31.7	31.6	31.5	31.0	30.5	30.3	30.0	30.0	29.7	30.0
February	27.9	27.2	26.7	26.2	25.7	25.2	25.0	24.7	25.2	26.6	28.0	29.2	30.5	31.4	32.0	32.6	32.9	32.3	31.3	30.6	30.2	29.8	28.9	28.0	28.7
March	29.3	28.8	28.6	28.2	28.1	27.6	27.6	27.5	28.3	29.5	30.4	31.1	32.1	32.6	32.9	33.0	33.3	33.1	32.5	32.2	31.7	31.3	31.0	30.4	30.5
April............	45.8	45.6	45.2	44.9	44.1	43.9	43.9	44.5	45.0	45.8	47.3	47.7	47.9	48.7	48.7	49.2	49.5	49.6	48.8	48.0	47.7	47.1	46.7	46.5	46.8
May.............	52.7	52.3	51.5	51.0	50.3	49.8	49.7	50.6	51.3	52.8	53.5	53.8	53.9	54.8	54.8	55.3	55.9	54.8	54.3	53.8	53.8	53.6	53.3	53.1	52.9
June	65.0	64.2	63.9	63.6	63.1	62.7	62.5	63.2	63.6	64.8	65.9	66.5	67.1	67.7	67.6	67.6	67.4	67.0	66.8	66.2	66.2	66.1	65.6	65.1	65.4
July	65.4	64.6	64.0	63.5	62.9	62.7	63.2	64.9	65.9	67.3	68.0	68.4	68.5	68.7	69.0	69.4	69.5	69.3	69.2	68.7	68.1	67.7	67.1	66.4	66.8
August..........	67.1	66.3	65.5	64.8	64.4	64.2	64.7	66.1	68.8	70.0	70.8	71.3	71.8	71.9	72.5	72.8	72.9	72.4	71.5	70.5	69.9	69.2	68.4	67.6	69.0
September	67.4	66.8	66.2	65.6	65.0	64.1	63.5	64.5	66.4	68.9	70.7	71.6	72.6	72.9	73.0	73.2	73.2	72.7	71.8	70.7	69.9	69.5	68.9	68.1	69.0
October	51.3	51.0	50.0	49.4	48.8	48.1	47.5	47.7	49.1	51.0	52.6	53.9	55.3	56.3	57.4	57.9	57.8	57.3	56.0	54.4	53.3	52.4	51.9	51.2	52.6
November	33.4	32.7	31.9	31.3	31.3	31.2	31.1	31.0	31.7	32.6	33.6	34.7	35.5	36.2	36.3	36.5	36.4	36.5	35.9	35.5	35.1	34.7	34.1	33.7	33.9
December.......	34.3	33.8	33.3	33.2	32.8	32.5	32.2	32.3	32.5	33.6	35.1	36.1	37.0	38.2	38.8	39.0	38.7	38.2	37.3	36.9	36.6	36.5	36.2	35.7	35.5
Year	47.4	46.9	46.4	45.9	45.5	45.1	45.0	45.4	46.4	47.6	48.8	49.5	50.2	50.9	51.2	51.5	51.6	51.2	50.5	49.8	49.4	49.0	48.5	48.0	48.4

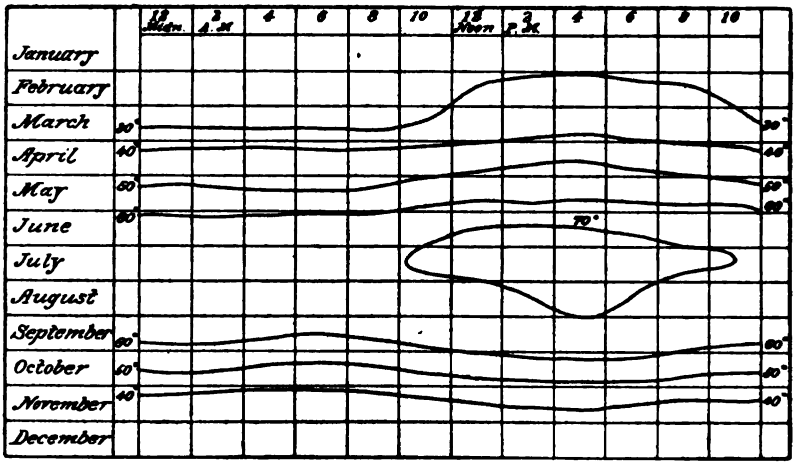


FIG. 12.—*Chrono-isotherms, Chicago,* 1890 *and* 1891.

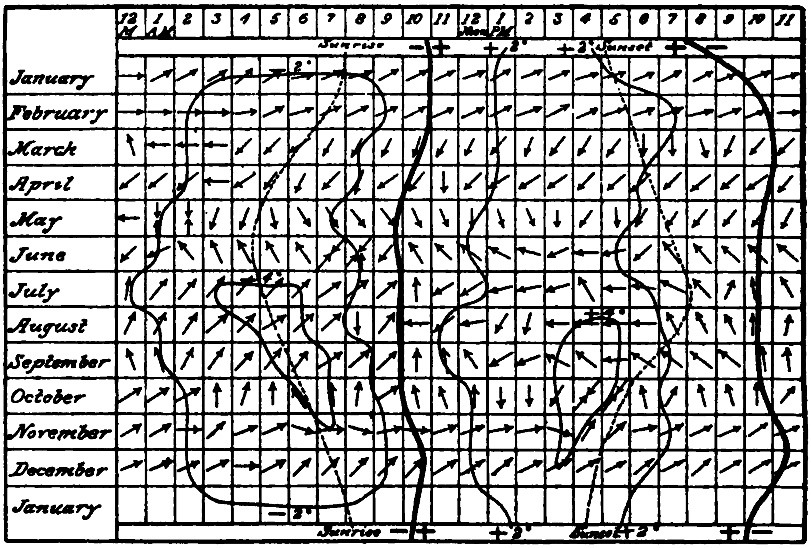


FIG. 13.—*Departure of mean temperature for each hour from the mean for the day at Chicago for* 1890.

We see very clearly shown, in Fig. 13, the effect of the lake breezes in keeping down the afternoon temperature. The curve of 4° showing the maximum departure is below August, and quite small. The effect of the lake in moderating extremes of temperature will be shown best by comparing the conditions here with those at other stations situated on the ocean or lakes. Fig. 14 is for Eastport, Me.; Fig. 15, Buf-

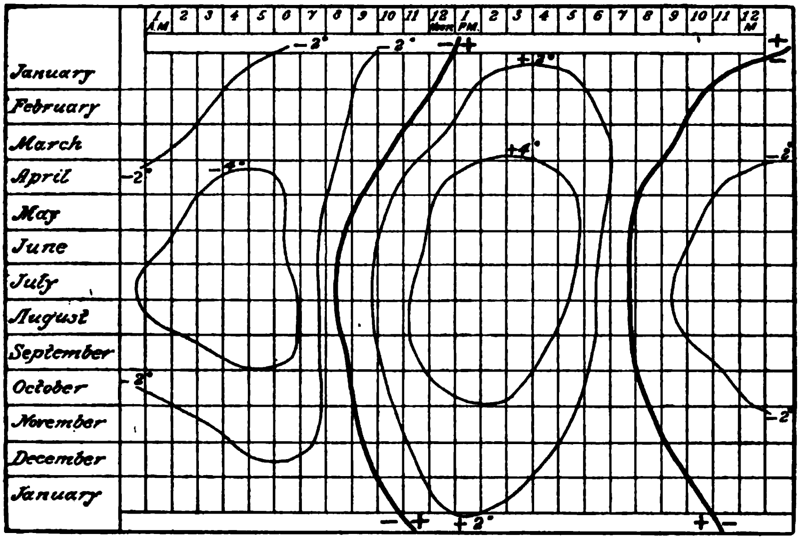


FIG. 14.—*Departure of mean temperature for each hour from the mean for the day at Eastport, Me., for* 1890.

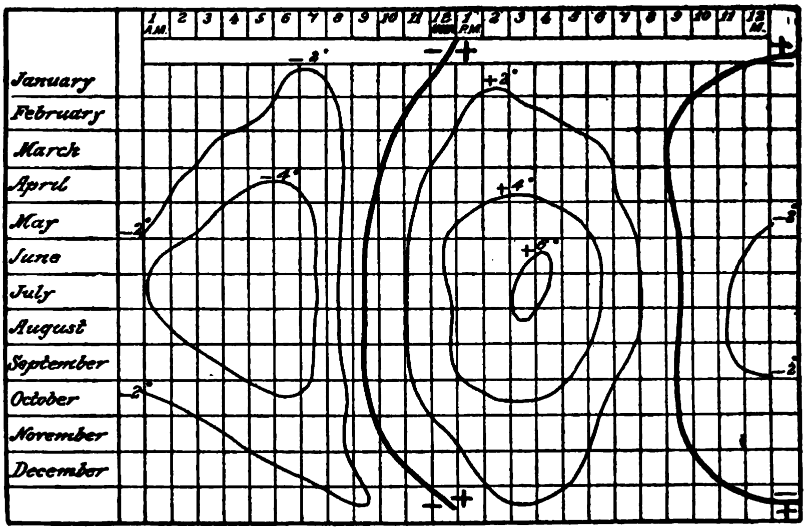


FIG. 15.—*Departure of mean temperature for each hour from the mean for the day at Buffalo, N. Y., for* 1890.

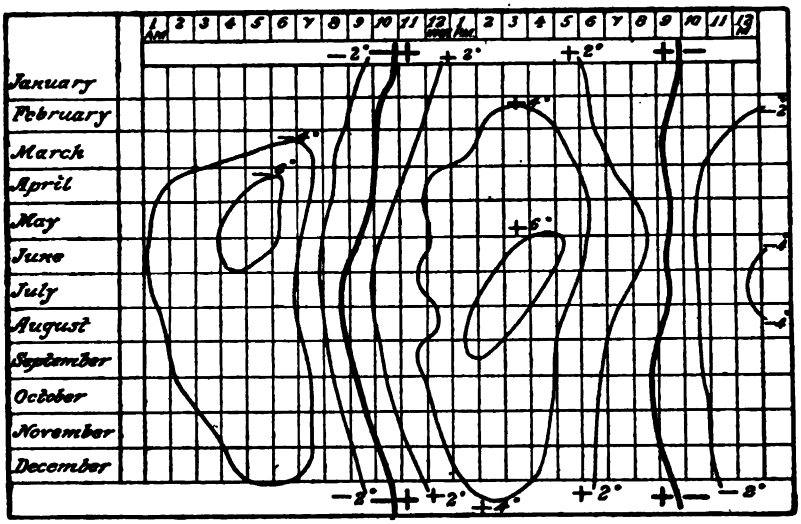


FIG. 16.—*Departure of mean temperature for each hour from the mean for the day at Boston, Mass., for* 1890.

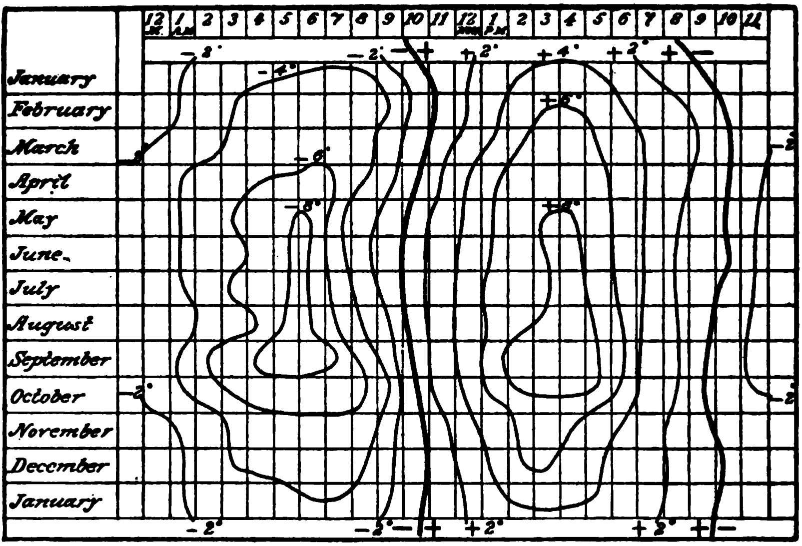


FIG. 17.—*Departure of mean temperature for each hour from the mean for the day at Saint Louis, Mo., for* 1890.

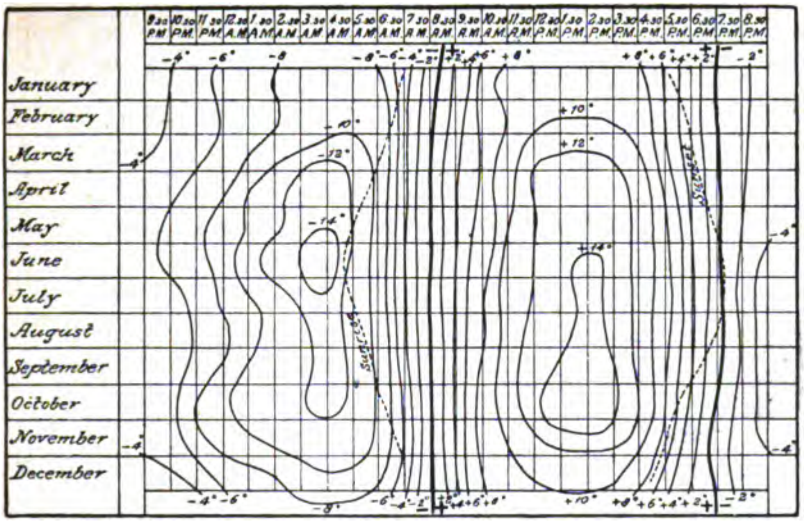


FIG. 18.—*Departure of mean temperature for each hour from the mean for the day at Yuma, Ariz., for* 1890.

falo, N. Y.; Fig. 16, Boston, Mass.; Fig. 17, Saint Louis, Mo.; and, by contrast, Fig. 18 is given for Yuma, Ariz. It will be seen that at all these stations the range from the lowest morning temperature to the highest in the afternoon is less for Chicago than for any other. The extreme range of about 29° at Yuma and about 11° at Buffalo corresponds to one of only 8° at this station.

PRECIPITATION AT CHICAGO.

Consistent records of rain and snow fall can scarcely be said to begin at Chicago before January, 1867. Prior to that date observations of this element were taken, and, in some cases, records were kept for one or more months, but never for a whole year. The cases in which monthly values have been preserved are the following:

1844, March and April; 1856, November and December; 1857, January to June, inclusive; and 1862, October.

Beginning with January, 1867, observations were taken by several observers reporting to the Smithsonian Institution. This series, which may be distinguished as the Voluntary Observers' period, was maintained without interruption to and including August, 1871; resumed in February, 1872, it was continued through December, 1874, with the single exception of March of the latter year.

Examining the overlapping period of the two systems of records, the differences shown in Table XXXIII are found; in this the Weather Service has been considered the standard record, and the amount of divergence of the Voluntary Observers' record is given with the sign appropriate to its direction.

Table XXXIII.—*Difference between Weather Service and Voluntary Observers' record.*

Year.	January.	February.	March.	April.	May.	June.	July.
1871	+4.64	+0.77	−0.82	−0.35	+0.31	+0.03	−0.36
1872	....	−0.15	−2.10	+0.08	+0.04	−0.04	+0.05
1873	+0.03	−0.06	+0.48	−3.12	+1.90	+0.36	−0.09
1874	+2.93	+1.80	....	−1.88	−1.06	+3.95	+1.12

Year.	August.	September.	October.	November.	December.	Annual.
1871	....	....	....	....	....	....
1872	−0.10	+0.61	0.00	+0.19	+1.38	+2.15
1873	+0.22	−0.13	−1.13	+0.89	−1.54	−2.19
1874	−1.45	−0.46	−1.85	−0.03	−0.63	....

Combination of these two systems gives for Chicago a period of 24 years during which observations have been directed upon the precipitation. Any attempt, such as the present, to arrive at an estimate of the precipitation in the period prior to the beginning of observation, must depend on the character and extent of the records maintained at stations sufficiently near to be considered typical of the same climatic district, and at the same time overlapping the existing records of the place under examination to such an extent as will admit of establishing, at least approximately, a ratio of variation.

It should be noted that these values for precipitation in Table XXXIV can not be considered entirely satisfactory, not only because of the difficulty of extrapolating the values, but also because the rain gauges have not always had a good exposure. A correct value of the precipitation for this station is still a great desideratum.

The rainfall by lustra, or 5-year periods, is as follows: 1871–1875, 33.56 inches; 1876–1880, 37.59 inches; 1881–1885, 42.07 inches; 1886–1890, 30.88 inches.

HEAVY PRECIPITATION.

In order to obtain an idea of the number of heavy rains that have fallen, Table XXXV has been prepared, which gives the dates on which a precipitation of .75 inch or more occurred in 8, or, since July, 1888, in 12 hours. There are 167 cases in the 20 years, or about 8 per year. The distribution by months is as follows:

January	3	August	19
February	5	September	17
March	8	October	19
April	14	November	6
May	20	December	5
June	21		——
July	30	Total	167

TABLE XXXIV.—*Precipitation from* 1843 *to* 1891, *Chicago.*

(All observed values are given to hundredths.)

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1843	2.0	1.9	3.0	4.5	4.0	4.6	1.4	2.4	3.0	1.2	5.1	2.4	35.50
1844	2.8	1.3	1.76	2.76	6.0	5.5	5.0	4.2	0.8	1.6	0.7	0.7	33.12
1845	2.0	0.5	2.2	6.5	2.0	3.8	3.5	1.2	4.4	1.4	3.3	1.5	32.30
1846	4.9	1.8	2.6	7.8	2.4	4.3	2.9	1.0	5.0	0.8	1.5	5.0	40.00
1847	2.3	3.5	1.5	2.1	3.3	1.5	2.8	2.0	3.2	4.6	4.8	1.2	32.80
1848	1.6	2.4	4.5	3.3	3.8	4.4	3.4	5.1	2.2	3.2	2.1	8.4	44.40
1849	5.5	1.0	4.7	1.8	3.8	3.6	2.3	3.5	2.6	2.8	1.4	1.2	34.20
1850	2.1	0.7	2.0	3.8	1.9	3.1	2.1	6.4	1.4	2.0	3.2	1.7	30.40
1851	1.5	3.8	0.8	4.2	6.7	5.3	3.8	3.1	3.2	2.3	2.3	1.6	38.60
1852	2.0	1.2	5.5	4.8	2.4	2.5	3.4	0.6	2.3	6.8	4.0	3.3	38.80
1853	1.4	2.2	1.8	2.8	4.4	4.9	6.1	2.2	4.2	2.0	2.1	2.3	36.40
1854	1.3	1.9	2.1	2.1	3.1	2.6	3.0	0.9	1.6	3.6	1.0	1.4	24.60
1855	8.0	0.6	2.6	1.4	2.5	3.7	5.8	3.2	2.3	2.0	2.2	2.0	36.30
1856	0.9	1.8	0.6	2.6	4.8	2.5	2.1	1.3	2.5	2.1	3.98	3.86	29.04
1857	1.09	5.43	2.5[illegible]	2.19	6.33	4.14	3.0	5.0	2.2	4.0	2.7	1.2	39.83
1858	1.3	1.4	3.0	3.1	7.8	6.3	5.9	3.2	4.0	4.6	4.5	2.0	47.10
1859	1.4	1.8	5.2	3.4	3.6	1.7	0.9	0.4	2.2	4.1	2.8	1.8	29.30
1860	1.6	1.6	1.0	2.8	4.6	3.5	5.3	2.6	2.8	4.1	2.3	4.2	36.40
1861	1.4	3.0	3.4	4.7	3.7	2.1	4.3	2.4	3.4	7.5	1.5	1.9	39.30
1862	4.0	0.7	2.0	5.2	4.3	2.9	6.7	3.6	5.6	2.92	1.2	1.3	40.42
1863	2.8	2.6	2.1	2.1	5.1	1.3	2.3	4.2	1.6	4.0	1.9	3.6	33.60
1864	1.6	0.4	2.1	3.2	1.9	2.1	6.4	1.1	2.1	1.9	3.1	2.5	28.40
1865	0.4	3.1	3.1	3.8	1.5	5.1	6.1	7.2	4.8	4.0	0.5	0.6	40.20
1866	2.8	1.6	2.2	2.8	2.0	4.4	4.7	4.2	4.6	2.8	0.8	3.4	36.30
1867	1.93	2.22	1.58	1.70	4.42	1.86	1.52	2.33	0.57	1.28	1.89	1.11	22.41
1868	1.28	0.92	5.24	3.00	3.74	3.11	2.87	3.55	7.08	1.69	2.60	1.40	36.48
1869	1.97	2.23	1.33	4.30	5.69	5.03	3.26	1.32	0.89	1.10	2.42	2.03	31.57
1870	1.95	0.86	1.81	1.15	0.80	1.70	3.71	2.07	2.82	2.43	1.16	2.46	22.92
1871	4.13	1.45	2.66	3.79	3.90	5.56	2.52	2.01	0.74	1.88	3.62	3.44	35.61
1872	0.68	0.84	3.79	3.03	3.24	3.45	3.09	2.59	6.43	0.65	1.06	0.22	29.07
1873	2.56	0.47	0.89	6.22	7.20	1.44	4.04	1.58	3.53	2.43	1.61	4.44	36.41
1874	3.47	1.51	2.15	2.67	2.08	3.25	0.58	3.15	3.76	2.55	2.83	0.63	28.63
1875	0.96	1.99	1.43	2.32	3.64	5.17	7.18	3.28	4.39	4.32	0.75	2.62	38.06
1876	3.22	3.90	4.04	2.07	1.85	5.96	3.11	3.66	3.74	1.20	3.25	0.48	36.48
1877	1.91	0.06	5.37	2.42	1.81	6.04	2.98	3.06	2.02	6.51	6.08	2.75	41.01
1878	1.31	2.12	4.39	5.57	5.22	3.02	6.09	3.66	1.99	5.17	0.83	2.58	41.95
1879	0.54	1.47	2.37	1.93	3.89	3.18	5.58	0.45	1.18	2.72	4.93	2.47	30.71
1880	3.53	2.91	2.25	5.20	4.97	3.50	3.07	4.47	2.25	3.19	0.87	1.11	37.32
1881	0.87	5.98	2.99	1.84	1.85	5.93	4.31	0.54	4.34	6.89	5.97	2.67	44.18
1882	1.55	2.24	3.43	6.72	5.52	5.71	3.43	4.96	0.91	3.40	1.48	1.99	41.34
1883	1.74	4.74	0.42	3.72	7.32	5.61	5.53	1.21	1.36	7.36	5.26	1.59	45.86
1884	1.39	3.27	5.16	3.05	1.53	2.11	3.71	2.50	2.29	3.59	1.80	4.21	34.61
1885	3.18	2.01	0.57	4.00	3.17	5.20	2.44	11.28	2.97	3.87	2.33	3.35	44.37
1886	3.56	1.51	1.79	1.29	1.00	0.94	1.53	3.38	6.93	1.42	1.66	1.76	26.77
1887	3.13	5.10	0.89	0.46	1.38	1.63	1.05	3.35	4.03	2.03	2.41	3.67	29.13
1888	1.56	1.51	2.99	2.13	6.22	1.66	3.93	2.10	0.98	2.95	2.89	1.94	30.86
1889	1.64	1.31	1.43	2.35	5.38	2.93	9.56	0.39	2.75	1.82	3.49	1.90	34.95
1890	2.98	2.42	2.10	3.23	5.13	3.25	2.57	2.58	1.39	4.20	1.59	1.25	32.69
1891	1.99	1.95	2.13	3.14	2.09	2.42	2.47	4.52	0.32	0.36	3.83	1.32	26.54
Mean, 1843 to 1866.	2.36	1.93	2.60	3.49	3.83	3.58	3.88	2.96	3.00	3.18	2.46	2.46	35.72
Mean, 1867 to 1891.	2.12	2.20	2.52	3.09	3.72	3.59	3.57	2.96	2.77	3.00	2.66	2.13	34.40
Mean, 1843 to 1891.	2.24	2.07	2.56	3.29	3.77	3.58	3.72	2.96	2.89	3.09	2.56	2.29	35.06

TABLE XXXV.—*Dates on which .75 inch or more precipitation occurred in 8 or 12 hours.*

Year.	Date.	Year.	Date.	Year.	Date.	Year.	Date.
1871..........	June 17	1876..........	June 16	1881..........	July 21	1885..........	July 9
1871..........	July 4	1876..........	July 10	1881..........	Sept. 24	1885..........	Aug. 2
1872..........	Mar. 30	1876..........	Aug. 24	1881..........	Oct. 11	1885..........	Aug. 23
1872..........	May 22	1876..........	Aug. 30	1881..........	Oct. 14	1885..........	Aug. 24
1872..........	May 29	1876..........	Sept. 13	1881..........	Nov. 11	1885..........	Sept. 8
1872..........	June 6	1877..........	June 8	1881..........	Dec. 21	1885..........	Oct. 19
1872..........	June 13	1877..........	June 25	1882..........	Feb. 28	1885..........	Nov. 5
1772..........	July 20	1877..........	July 2	1882..........	Apr. 5	1885..........	Dec. 8
1872..........	Aug. 28	1877	Aug. 14	1882..........	Apr. 9	1886..........	Aug. 16
1872..........	Sept. 12	1877..........	Sept. 26	1882..........	Apr. 23	1886..........	Sept. 9
1872..........	Sept. 28	1877..........	Oct. 3	1882..........	Apr. 26	1886..........	Sept. 18
1873..........	April 11	1877..........	Oct. 19	1882..........	May 6	1886..........	Sept. 19
1873..........	May 1	1877..........	Nov. 8	1882..........	May 27	1887..........	Jan. 22
1873..........	May 9	1878..........	Mar. 28	1882..........	June 3	1887..........	Feb. 17
1873..........	July 4	1878..........	May 18	1882..........	June 30	1887..........	Aug. 11
1873..........	Sept. 28	1878..........	May 29	1882..........	July 31	1887..........	Aug. 14
1873..........	Oct. 4	1878..........	July 26	1882..........	Aug. 1	1888..........	May 27
1873..........	Dec. 8	1878..........	Aug. 18	1882..........	Aug. 23	1888..........	May 28
1873..........	Dec. 11	1878..........	Aug. 25	1882..........	Oct. 8	1888..........	July 4
1873..........	Dec. 12	1878..........	Sept. 25	1883..........	Feb. 16	1888..........	July 9
1874..........	Mar. 3	1879..........	Mar. 6	1883..........	Apr. 5	1888..........	July 31
1874..........	Apr. 20	1879..........	Apr. 9	1883..........	May 9	1889..........	May 13
1874..........	June 7	1879..........	May 25	1883..........	May 10	1889..........	May 27
1874..........	June 8	1879..........	June 21	1883..........	June 18	1889..........	July 3
1874..........	Aug. 21	1879..........	July 6	1883..........	July 4	1889..........	July 14
1874..........	Sept. 4	1879..........	July 7	1883..........	July 21	1889..........	July 19
1874..........	Oct. 28	1879..........	July 9	1883..........	July 23	1889..........	July 27
1875..........	May 1	1879..........	July 21	1883..........	Aug. 27	1889..........	July 28
1875..........	June 1	1879..........	Oct. 17	1883..........	Oct. 2	1889..........	Sept. 4
1875..........	June 21	1879..........	Nov. 28	1883..........	Oct. 25	1889..........	Sept. 5
1875..........	July 5	1880..........	Mar. 27	1883..........	Oct. 29	1889..........	Oct. 12
1875..........	July 6	1880..........	Apr. 16	1883..........	Nov. 5	1890..........	Apr. 13
1875..........	July 27	1880..........	Apr. 24	1884..........	Mar. 25	1890..........	May 10
1875..........	Aug. 15	1880..........	May 8	1884..........	Apr. 15	1890..........	June 3
1875..........	Sept. 9	1880..........	May 10	1884..........	July 24	1890..........	June 11
1875..........	Oct. 29	1880..........	July 8	1884..........	Aug. 28	1890..........	July 14
1876..........	Jan. 18	1880..........	Oct. 1	1884..........	Sept. 27	1890	Aug. 21
1876..........	Feb. 9	1880..........	Oct. 3	1884..........	Oct. 8	1890..........	Sept. 8
1876..........	Mar. 16	1881..........	Feb. 7	1885..........	Jan. 6	1890..........	Oct. 6
1876..........	Apr. 13	1881..........	Mar. 19	1885..........	Apr. 17	1890..........	Oct. 26
1876..........	June 1	1881..........	June 7	1885..........	May 29	1890..........	Nov. 17
1876..........	June 8	1881..........	June 13	1885..........	June 2		

To obtain an idea of the cases of precipitation of 2.50 inches or more in 24 hours, Table XXXVI has been prepared. This shows 15 cases in 20 years, by months:

January..............................	0	July..................................	8
February............................	0	August................................	2
March	1	September..........................	2
April..................................	0	October..	1
May....................................	2	November	2
June..	1	December............................	1

These figures show that the heavier rain comes with the local thunder showers of the warmer months. There is no contradiction in this, with the fact that we have less rain with the lake wind in summer, as has already been shown, for with these local storms the wind is from the west.

TABLE XXXVI.—*Dates on which* 2.50 *inches or more precipitation occurred in* 24 *hours at Chicago to December*, 1890, *inclusive.*

Year.	Date.	Year.	Date.	Year.	Date.	Year.	Date.
1871	Dec. 22	1875	Sept. 10	1879	July 7	1885	June 1
1871	Dec. 23	1877	Oct. 19	1881	Nov. 11	1885	June 2
1872	Sept. 28	1877	Oct. 20	1881	Nov. 12	1885	Aug. 2
1872	Sept. 29	1878	July 25	1883	Nov. 5	1885	Aug. 3
1873	May 1	1878	July 26	1883	Nov. 6	1885	Aug. 23
1873	May 2	1879	May 25	1884	Mar. 25	1885	Aug. 24
1875	Sept. 9	1879	July 6	1884	Mar. 26	1889	July 27

WIND VELOCITY.

The exposure of anemometers has been so frequently changed that it will be very difficult to compare the earlier records, with the anemometer relatively near the ground, with the later records. Table XXXVII gives the total movement for each month during 19 years. Table XXXVIII gives the hourly wind movement for the years 1889, 1890, and 1891. After February, 1890, these records were made on the Auditorium tower. Fig. 19 is a graphic presentation of these figures.

TABLE XXXVII.—*Total wind movement, in miles, for Chicago.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	Sept.	October.	November.	December.	Annual.
1873	10,529	7,980	10,938	7,706	8,555	5,423	5,908	4,455	6,720	6,520	5,520	6,799	87,053
1874	7,135	5,520	7,724	7,507	7,102	6,187	6,689	6,729	5,982	6,246	7,049	7,341	81,211
1875	5,873	6,590	7,926	7,042	6,310	6,034	5,072	6,234	5,739	7,669	6,585	7,014	78,088
1876	6,732	5,860	6,736	6,389	6,297	5,494	5,023	4,154	4,885	6,272	5,340	5,903	69,085
1877	6,668	6,531	7,737	6,820	6,201	5,832	5,277	4,855	5,600	6,845	6,747	6,896	76,009
1878	7,008	6,202	7,182	6,414	5,093	4,607	4,541	4,599	5,220	6,670	4,847	5,284	67,667
1879	4,999	5,106	5,440	5,668	5,434	5,132	4,586	4,762	4,895	4,625	5,354	6,154	62,155
1880	5,232	6,053	6,823	8,214	6,141	5,094	5,028	5,726	6,046	6,902	6,614	6,319	74,192
1881	5,358	5,723	5,774	5,083	5,568	5,768	4,862	5,501	5,906	5,768	7,619	6,606	69,536
1882	6,926	6,625	7,778	7,275	7,232	5,916	5,573	4,997	5,695	5,733	6,095	6,377	76,222
1883	7,140	5,789	6,704	7,328	6,705	5,972	5,901	4,508	4,783	5,925	6,440	5,945	74,140
1884	6,713	5,412	6,168	6,364	6,016	4,496	4,293	4,996	5,800	5,745	5,441	6,574	68,018
1885	7,316	4,934	5,493	6,292	5,406	4,649	4,233	6,092	5,726	6,136	6,185	6,700	69,162
1886	7,498	6,895	6,854	6,148	5,752	4,932	5,472	5,432	5,543	5,568	6,924	5,111	72,129
1887	9,248	7,463	8,271	8,786	6,915	6,463	7,161	6,579	7,849	9,025	9,192	2,959?	89,911
1888	8,294	7,702	8,931	9,112	7,507	7,383	6,450	7,730	6,670	8,210	7,404	8,360	93,753
1889	7,807	7,394	7,985	7,936	9,771	5,614	5,979	5,290	5,609	7,096	7,488	7,664	85,633
1890	7,978	12,105	13,806	14,912	13,538	9,225	11,503	10,297	12,436	10,751	12,224	13,582	142,357
1891	11,142	13,357	14,319	12,043	11,865	9,961	9,670	9,228	10,184	12,899	14,425	15,935	145,028

TABLE XXXVIII.—*Hourly wind movement, in miles, for Chicago.*

Months.	24.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Mean
1889.																									
January	9.8	9.2	9.4	9.6	9.6	10.2	10.3	10.0	10.0	10.0	10.7	10.3	11.0	11.3	11.3	11.5	11.5	11.1	11.0	10.2	9.3	9.6	9.5	9.5	10.2
February	11.3	9.4	9.1	8.4	8.8	9.1	9.3	8.9	9.6	10.2	10.5	10.9	12.4	12.0	13.2	13.1	12.8	12.3	12.7	11.6	11.8	11.4	11.2	11.2	10.9
March	9.9	9.4	9.2	9.7	9.1	9.2	10.0	10.1	10.6	11.0	11.1	11.5	12.4	12.0	12.5	13.0	12.7	12.1	12.0	10.1	9.6	9.6	9.7	9.6	10.7
April	10.1	10.1	10.4	10.8	11.2	10.3	11.3	11.4	11.4	12.1	12.1	12.2	12.3	12.2	12.2	11.9	11.7	11.2	11.2	10.2	9.7	9.8	9.5	9.1	11.0
May	12.3	11.9	12.1	12.0	12.2	11.5	13.1	13.1	13.6	13.8	14.5	15.2	15.4	15.8	15.5	15.0	14.9	14.3	13.9	12.0	10.5	10.4	11.0	11.5	13.1
June	6.7	6.4	6.2	5.9	6.4	6.6	7.4	7.4	8.0	8.2	8.9	9.7	9.7	9.7	10.1	9.8	9.8	9.4	9.3	6.9	6.4	6.1	5.9	6.3	7.8
July	7.5	6.7	6.4	6.0	6.1	5.9	6.0	6.7	7.5	8.1	8.8	9.3	9.2	10.1	10.7	10.5	10.1	10.5	10.3	8.3	7.5	7.0	6.7	7.0	8.0
August	6.3	5.7	5.4	5.3	5.4	5.6	6.4	6.7	6.9	7.3	8.0	8.9	8.9	8.9	8.8	8.5	8.6	8.1	7.7	7.0	6.8	6.6	6.4	6.3	7.1
September	7.5	7.1	7.4	7.1	6.9	7.2	7.7	7.0	7.7	7.4	8.6	8.9	8.6	8.8	8.9	9.1	9.1	8.8	7.7	6.7	7.0	7.0	7.1	7.4	7.8
October	10.5	8.9	8.5	7.5	7.4	7.0	8.5	8.6	9.2	9.1	9.9	10.3	10.5	10.6	10.5	10.6	10.4	10.0	10.1	9.4	10.4	10.1	10.5	10.5	9.5
November	10.0	9.3	9.0	9.0	8.9	9.5	10.4	10.2	11.0	11.1	11.6	11.8	11.7	11.7	11.6	11.3	10.8	11.0	10.9	9.6	9.9	9.6	9.8	9.7	10.4
December	10.2	10.6	9.9	9.7	10.3	10.1	10.7	10.3	10.7	11.5	11.5	10.5	10.6	10.5	10.9	10.5	10.5	9.6	10.4	9.4	9.6	10.1	9.6	9.6	10.3
Year	9.3	8.7	8.6	8.4	8.5	8.5	9.3	9.2	9.7	10.0	10.5	10.8	11.1	11.2	11.4	11.2	11.1	10.7	10.6	9.3	9.0	8.9	8.9	9.0	9.7

TABLE XXXVIII.—*Hourly wind movement, in miles, for Chicago*—Continued.

Months.	24.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Mean.
1890.																									
January	11.0	10.3	10.1	10.3	9.6	9.9	11.0	10.9	10.6	10.9	11.2	11.3	11.2	10.9	11.5	11.4	10.8	10.8	11.7	10.9	10.4	10.2	10.0	10.3	10.7
February	18.0	17.5	17.0	17.4	17.6	17.1	17.8	17.8	18.5	18.0	18.0	18.3	19.4	19.2	19.9	18.2	18.1	17.3	18.0	16.8	17.8	18.2	18.6	18.2	18.0
March	19.1	18.7	18.8	19.0	17.9	17.9	20.3	18.5	18.8	19.2	19.0	19.1	19.7	19.0	20.5	20.2	19.4	18.9	19.5	16.6	16.3	15.7	15.8	17.5	18.6
April	21.3	19.8	20.5	20.4	21.2	21.6	22.1	20.1	19.8	19.5	19.7	20.1	19.9	20.4	21.4	21.4	21.5	20.9	21.5	19.8	20.6	21.0	20.9	21.8	20.7
May	19.2	17.4	17.5	17.7	18.2	18.1	18.2	17.0	16.3	17.7	18.8	19.8	19.8	20.0	20.5	20.5	19.2	18.7	18.6	15.2	15.6	17.0	17.6	17.9	18.2
June	12.3	12.7	12.2	11.9	11.3	12.4	12.6	11.5	11.8	11.3	12.5	13.6	14.2	14.4	15.2	16.4	15.6	15.0	13.7	11.3	10.6	11.4	12.0	11.6	12.8
July	16.7	16.7	16.6	16.1	15.9	15.8	16.4	14.7	13.6	13.9	13.7	14.3	14.8	15.4	16.6	16.8	16.7	17.0	16.5	14.7	13.7	14.3	14.5	15.3	15.4
August	15.5	13.6	13.3	13.4	13.7	14.0	14.9	12.8	12.2	13.0	12.9	13.3	13.7	14.0	14.4	15.2	15.7	14.8	14.6	13.2	14.1	13.0	13.3	13.6	13.8
September	19.4	17.9	17.1	16.8	17.4	17.0	18.6	16.9	17.1	17.1	17.5	16.8	16.5	16.4	17.6	18.1	17.3	16.0	16.6	15.1	17.8	18.1	17.8	17.8	17.3
October	15.1	14.6	14.4	14.0	13.7	14.3	14.6	13.6	14.4	14.5	14.5	15.5	15.9	16.9	16.2	15.2	14.4	13.3	14.0	13.5	13.5	13.4	13.7	14.0	14.5
November	17.7	16.7	16.8	16.5	16.6	16.7	17.8	16.7	17.5	17.3	17.5	17.5	18.0	17.8	18.2	18.0	17.3	16.3	16.6	15.5	15.4	15.9	16.5	16.8	17.0
December	18.6	17.3	16.6	16.8	16.5	17.4	18.2	17.2	17.3	17.1	17.8	18.7	18.5	18.4	19.4	19.5	19.8	19.4	20.1	19.1	19.3	18.8	18.0	18.3	18.3
Year	17.0	16.1	15.9	15.9	15.8	16.0	16.9	15.6	15.6	15.8	16.1	16.5	16.8	16.9	17.6	17.6	17.2	16.5	16.8	15.1	15.4	15.6	15.7	16.1	16.3
1891.																									
January	15.5	14.5	13.8	13.9	14.3	14.7	14.9	14.1	15.0	15.5	15.6	15.9	15.6	16.1	16.3	16.1	15.5	15.7	15.1	13.9	14.0	14.2	14.3	15.1	15.0
February	20.9	19.2	18.5	18.2	18.5	19.0	20.4	18.8	19.6	20.2	19.9	20.9	20.8	20.1	20.5	20.7	20.4	21.3	21.4	19.8	19.6	19.1	19.3	19.8	19.9
March	19.5	17.6	17.6	17.6	17.4	18.5	19.5	18.9	19.0	19.2	19.5	18.6	19.7	19.5	19.1	19.7	19.6	20.5	20.0	19.6	20.6	20.5	20.5	19.9	19.2
April	18.1	16.0	16.7	16.0	16.4	16.6	17.4	15.7	15.6	16.1	16.4	17.2	17.6	17.6	18.7	18.8	18.5	17.9	17.1	15.7	16.1	14.9	14.6	15.8	16.7
May	17.0	15.8	16.5	16.4	17.5	17.6	17.2	15.1	14.7	15.0	15.4	15.6	16.2	15.4	15.5	15.6	16.4	17.3	17.1	15.2	14.6	15.1	15.0	15.7	15.9
June	14.6	14.3	13.2	13.7	13.9	13.6	14.0	13.6	13.3	13.0	13.4	14.1	13.7	13.1	13.9	14.5	14.6	14.8	15.6	13.8	13.6	13.3	13.3	13.3	13.8
July	14.0	12.6	12.6	11.4	12.2	13.4	14.6	12.8	12.6	13.3	14.2	15.5	16.4	14.9	14.2	13.5	13.8	12.8	12.9	11.1	10.8	9.9	10.3	12.1	13.0
August	14.0	13.8	14.2	13.1	12.1	12.3	12.6	10.5	9.9	10.0	10.8	11.7	12.1	12.6	13.6	13.3	12.9	12.5	12.4	11.2	11.6	12.5	12.9	14.1	12.4
September	14.5	14.0	15.1	14.8	14.9	14.7	15.4	13.8	12.5	11.5	11.9	13.8	14.9	15.2	15.9	16.1	15.5	14.1	13.1	13.1	12.9	13.9	14.3	13.9	14.1
October	17.2	17.2	17.6	16.9	16.3	16.3	17.6	17.4	17.4	17.6	17.5	18.1	19.1	19.0	18.8	18.6	17.4	16.5	16.2	16.0	16.2	16.6	17.2	17.5	17.3
November	21.2	20.3	20.4	21.4	20.9	20.9	21.8	20.0	20.1	20.4	20.6	20.8	20.8	19.9	19.9	19.1	19.0	18.5	18.9	18.1	18.4	19.3	19.6	20.5	20.0
December	22.8	21.4	21.9	20.8	20.7	29.1	21.6	19.9	20.3	20.6	21.7	22.8	22.9	22.2	22.6	20.9	20.8	29.4	21.6	20.2	21.7	21.7	22.3	22.1	21.4
Year	17.4	16.4	16.5	16.2	16.3	16.5	17.2	15.9	15.8	16.0	16.4	17.7	17.5	17.1	17.4	17.2	17.0	16.9	16.8	15.6	15.8	15.9	16.1	16.6	16.6

In 1889 we find the appearance of the diurnal range of wind velocity that has been noted generally at other stations, though there is a slight maximum cropping out at midnight and 6 a. m. The curves for 1890 and 1891 have two remarkable maxima besides the

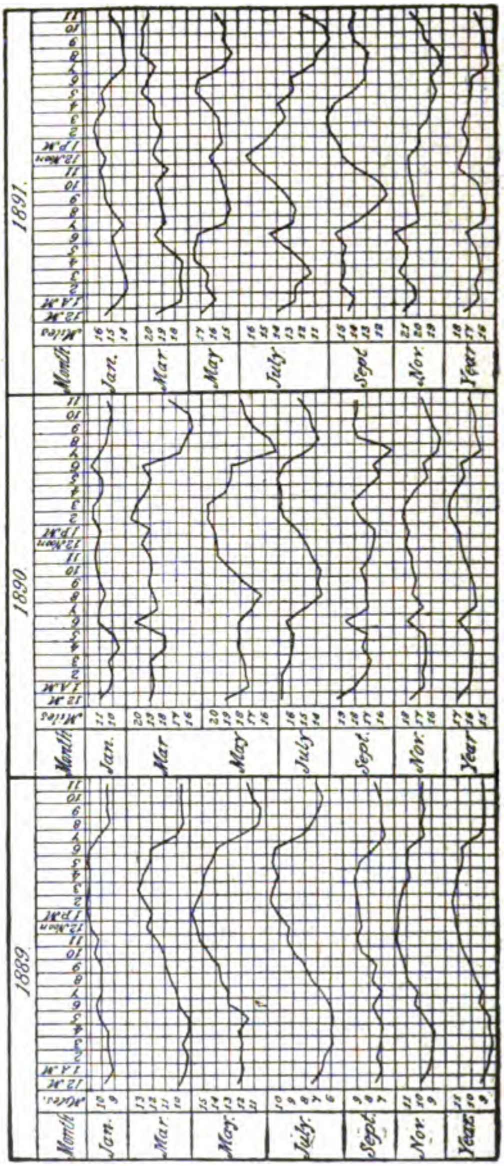


FIG. 19.—Hourly wind velocity, Chicago.

usual one at 2 p. m., one at midnight and another at 6 a. m. There is some difficulty in explaining these secondary maxima rising in 1891 to almost the same height as the principal maximum. We need a good many more records, and, above all, at different heights above the lake surface. A morning maximum was found by Professor Harrington at Death Valley (see p. 36, Bulletin No. 1), though there the maximum occurred two hours later than here. It is probable that the presence of the lake has something to do with the minimum at 7 p. m. (19 hours). Any wind from the north-northeast to east-southeast, and from south-southwest to west-northwest, would be slightly accelerated because of the less friction on the water, and the occurrence of winds from this direction at midnight or 6 a. m. would increase the velocity. The morning maximum may be due to the same cause as that producing the higher velocity on mountains, or else the upper current, which has a greater relative velocity, may gradually work down toward the earth's surface in the morning, as the air cools off and is contracted. The fact that this effect was almost *nil* in 1889, when the anemometer was farther from the lake and more than 100 feet lower, seems to indicate some such explanation as this. It is probable that the tower 400 feet high to be built in Chicago may assist in solving this problem.

In order to determine whether the direction of the wind had anything to do with these anomalous results, Table XXXIX was prepared, giving the wind velocity according to the hour of the day and its direction for each month, from April–October. The bold face figures show maxima in the velocity in the morning. It will be seen that these occur without respect to the direction. The afternoon minimum, however, seems to be slightly more marked with the land winds.

TABLE XXXIX.—*Velocity of wind, in miles, for each hour and direction, Chicago.*

Direction.	24.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Mean
APRIL, 1890.																									
North	22	......	23	......	7?	......	29	22	20	20	22	......	17	21	21	16	18	25	......	7?	......	7	8	8	22.8?
Northeast	22	22	23	22	25	25	25	22	22	22	19	20	20	21	23	24	22	21	24	22	24	24	24	24	22.5
East	19	18	20	19	13	19	19	17	16	14	12	13	12	6	10	10	9	13	15	13	11	9	10	10	15.8
Southeast	15	15	13	15	20	16	16	14	14	15	14	12	10	12	15	14	9	9	15	11	12	15	17	21	13.9
South	18	18	16	17	14	17	17	12	16	15	20	24	22	21	24	6	27	27	23	21	22	13	13	9	20.2
Southwest	30	24	25	27	27	28	38	32	23	26	29	32	33	32	30	31	30	25	34	29	26	26	28	29	27.8
West	21	20	......	......	......	......	18	16	9	11	14?	15	17	16	17	17	17	13	......	......	......	......	......	......	14.8
Northwest	......	17	14	16	14	......	14	......	......	......	19	14	15	14	......	......	......	......	......	10	......	......	......	......	18.5
MAY, 1890.																									
North	17	13	16	13	17	15	18	15	......	11	8	......	......	15	......	9	......	......	15	17	14	19	18	15	15.7
Northeast	25	20	22	21	21	21	22	21	22	23	26	21	21	20	20	19	18	17	18	18	20	19	19	18	19.9
East	......	......	......	6	......	......	25	......	......	......	10	8	12	11	10	8	11	13	22	13	11	15	11	8	13.2
Southeast	19	13	11	13	15	17	13	11	11	7	9	14	15	13	13	15	9	11	14	10	10	7	14	12	12.0
South	15	15	15	18	20	15	18	17	16	23	25	......	26	......	14	25	26	......	15	12	17	11	17	16	18.7
Southwest	26	21	21	21	20	22	21	21	20	19	23	25	21	26	28	28	27	24	26	20	22	22	23	24	22.6
West	17	16	15	18	18	17	18	15	13	14	14	20	19	17	18	20	13	17	18	13	13	22	16	17	17.8
Northwest	7	11	13	13	12	12	15	14	12	14	17	15	16	13	......	18	21	20	23	19	12	11	......	21	14.7
JUNE, 1890.																									
North	......	10	9	11	9	......	......	8	5	......	8	7	......	......	......	23	12	......	......	9	7	7	3	7	10.9
Northeast	8	6	9	7	6	6	10	8	8	6	7	11	12	14	12	13	13	12	12	11	10	11	8	9	11.3
East	11	8	9	11	11	13	9	6	13	4	2	5	6	7	10	6	8	11	12	7	6	8	9	9	10.5
Southeast	9	15	7	10	10	11	13	13	10	8	9	10	9	10	[illegible]	13	15	14	11	11	11	15	9	7	11.9
South	12	19	21	13	12	13	11	13	17	19	18	13	8	8	29?	32?	33?	3	18	7	10	14	18	14	15.4
Southwest	17	18	18	16	15	17	17	16	18	16	19	21	20	22	22	25	22	23	19	20	17	23	15	15	20.8
West	11	9	13	14	14	16	14	10	11	12	11	10	19	14	31?	......	......	17	16	11	7	7	......	23	14.4
Northwest	15	14	9	6	9	9	12	4	8	4	14	5	15	11	12	11	18	26	14	......	17	12	16	14	10.5
JULY, 1890.																									
North	11	10	7	10	8	9	......	7	7	15	16	......	12	12	14	15	15	14	6	20	12	11	12	13	16.0
Northeast	15	18	18	17	19	19	17	17	16	14	14	15	15	17	18	19	17	15	19	16	18	19	17	16	17.1
East	20	......	......	......	18	......	21	18	11	12	12	7	7	9	7	11	9	10	12	10	7	3	......	......	11.7
Southeast	12	12	12	15	17	17	18	12	12	13	9	12	11	7	9	9	12	15	12	11	10	10	10	9	10.8

South...........	17	20	12	14	**16**	13	10	10	13	15	17	......	18	27	16	......	15	16	19	18	14	19	19	22	16.3
Southwest......	23	22	22	20	18	**19**	**20**	18	13	14	17	20	20	21	25	21	22	24	21	18	16	16	17	23	20.8
West............	13	17	......	......	**16**	**15**	7	12	18	12	12	14	15	15	16	16	19	......	21	14	12	12	10	8	15.1
Northwest......	15	14	13	12	11	**15**	**15**	**15**	12	18	17	13	17	......	......	17	15	15	12	......	......	15	11	12	14.2

AUGUST, 1890.

North...........	18	17	......	21	14	**16**	......	......	15	13	17	17	13	11	9	16	17	......	19	......	......	18	17	15	15.1
Northeast	20	17	17	15	11	**15**	**17**	**14**	13	16	15	15	15	16	16	15	15	14	16	16	20	18	20	20	16.1
East	14	18	13	12	**17**	**14**	**15**	**15**	8	11	12	9	10	10	11	12	10	11	10	12	12	13	12	11	12.0
Southeast.......	12	11	8	14	8	8	**15**	8	10	10	9	10	9	8	8	11	11	10	14	11	12	9	10	11	10.1
South	13	11	18	15	15	13	**14**	10	12	11	11	12	11	......	14	16	22	20?	......	12	11	9	8	8	14.3
Southwest	14	13	12	13	13	**15**	**20**	**16**	14	15	19	18	18	19	23	24	21	21	14	14	15	13	13	14	18.9
West	16	12	9	10	**15**	**15**	**18**	10	12	15	13	17	20	17	14	......	32?	15	20	14	14	17	17	21?	15.2
Northwest......	20	16	13	10	12	**14**	**14**	**14**	11	13	12	13	13	......	......	......	34?	......	......	......	......	11	9	20?	13.1

SEPTEMBER, 1890.

North...........	15	14	12	12	14	14	**16**	13	16	13	10	4	19	15	14	17	14	14	17	11	16	16	13	12	15.0
Northeast	20	17	19	18	21	**21**	**24**	**23**	19	20	20	18	17	17	20	18	18	18	19	18	19	20	18	18	18.9
East	15	14	16	18	13	14	15	15	**17**	**17**	**18**	15	7	10	12	11	10	10	12	25?	26	23	16	20	16.2
Southeast.......	19	18	17	17	17	13	11	......	14	......	22	24	8	14	12	13	15	13	12	12	17	17	16	17	14.1
South	21	17	17	16	17	**18**	**21**	12	16	10	9	7	16	20	23	20	......	14	16	14	15	17	19	18	16.8
Southwest	24	23	18	18	18	17	17	17	16	**18**	**19**	17	17	16	19	20	20	18	16	16	15	18	17	18	18.3
Wes.	......	12	12	16	18	19	**23**	**22**	**25**	**24**	22	24	21	18	10	......	19	17	18	14	......	......	......	......	19.5
Northwest......	13	......	......	......	......	......	......	......	......	9	......	......	......	31?	24	31?	25	17	18?	11	15	13	24	22	19.5

NOVEMBER, 1890.

North...........	22	19	29	17	**18**	**18**	**21**	17	17	19	20	17	18	10	16	14	15	14	13	4?	14	11	14	12	16.8
Northeast	22	18	18	22	12	......	**23**	17	......	18?	18	31	28	16	17	17	19	17	17	21	21	21	21	20	19.4
East	16	......	......	......	19?	**20**	**20**	15?	**21**	12?	10	19	14	19	16	21	22	22	11	12	15	9	11	10	15.1
Southeast.......	......	19?	14	8	5?	......	8	3?	10	3?	......	3?	......	......	7	10	8	7	......	13	10	12	12	17	15.9
South	16	15	16	16	16	17	**34**	9	**22**	**5?**	5?	......	11	10	......	12	7	7	15	15	13	12	16	16	15.6
Southwest	17	17	18	18	21	20	16	**24**	**24**	**23**	20	19	22	21	20	21	19	17	16	16	17	21	17	19	19.8
West	21	18	19	19	17	17	**18**	15	15	20	17	17	17	18	18	18	18	17	17	16	16	18	18	18	17.7
Northwest......	14	12	14	13	14	14	**15**	13	13	11	15	15	14	16	25	18	18	17	17	17	17	16	17	16	14.6

NOTE.—Bold face figures show that the increase in velocity in the air is the same for all directions.

To show the effect of the different months upon the hourly wind direction, Fig. 20 has been prepared. This gives, in graphic form, the departure of the daily mean from each hourly record. In this figure the principal maximum between 2 and 3 p. m. stands out very prominently as well as the minima at 8 a. m. and p. m. The curve

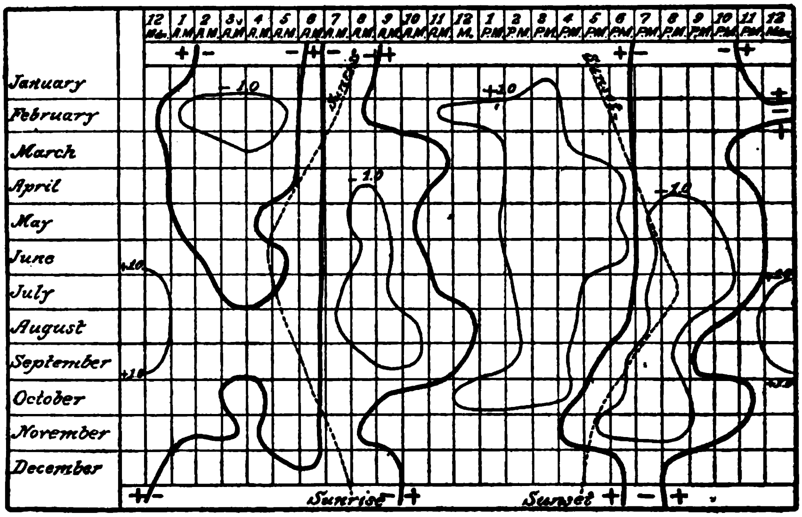


FIG. 20.—*Departure of hourly wind velocity from the daily mean, Chicago.*

of sunrise and sunset is here given dotted. The principal minimum occurs very soon after sunset, especially in the warmer months, while the morning maximum comes about sunrise; but the serious difficulty is in trying to explain the prominent minimum at 8 a. m. It is a matter of observation that during many winds there is a dying down at sunset to be followed by a decided freshening at sunrise.

VELOCITY OF WIND AT DIFFERENT HOURS.

The question has been asked as to the velocity of the higher winds during the day hours, especially in determining the possibility of running windmills. Table XL has been prepared with this in view, and shows the number of times the wind blew at different velocities during the hours of the day, and in two or more locations of the anemometer. These figures show a great increase in the occurrence of the higher winds as the height of the anemometer is increased.

The last column of this table gives the percentage of winds of each velocity during the month. For example, 25 per cent. of the winds in January were from 0 to 7, 57 per cent. were from 8 to 14, etc.

TABLE XL.—*Wind movement at different hours of the day*, 1884 *to* 1889.

(Number of times observed blowing from 0 to 7 miles per hour.)

Month.	11 to midnight.	3 to 4 a.m.	7 to 8 a.m.	11 to noon.	3 to 4 p.m.	7 to 8 p.m.	Total.	Per cent.
January	31	42	35	27	24	28	187	25
April	83	79	75	43	40	73	393	36
July	124	134	124	77	50	104	613	55
October	89	87	84	48	46	88	442	39
Mean	81.8	85.5	79.5	48.8	40.0	73.2	....	39
From 8 to 14 miles.								
January	69	66	68	76	65	79	423	57
April	70	74	72	81	89	80	466	43
July	53	50	56	89	111	71	430	38
October	73	86	81	100	98	76	514	46
Mean	66.2	69.0	69.2	86.5	91.0	76.5	....	46
From 15 to 20 miles.								
January	22	11	16	15	27	13	104	14
April	24	19	24	41	37	20	165	15
July	9	2	5	19	22	11	68	6
October	20	12	16	33	31	18	130	12
Mean	18.8	11.0	15.2	27.0	29.2	15.5	....	12
Above 20 miles.								
January	2	5	5	6	8	4	30	4
April	3	8	9	15	14	7	56	5
July	0	0	1	1	3	0	5	1
October	4	1	5	6	10	4	30	3
Mean	2.2	3.5	5.0	7.0	8.8	3.8	....	3

Wind movement at different hours of the day, 1890 *and* 1891 (*Auditorium*).

Number of times observed blowing from 0 to 7 miles per hour.

Month.	11 to midnight.	3 to 4 a.m.	7 to 8 a.m.	11 to noon.	3 to 4 p.m.	7 to 8 p.m.	Total.	Per cent.
January	12*	14	16	12	11	16	81	22
April	5	6	7	3	3	7	31	9
July	14	16	13	11	12	15	81	22
October	7	5	9	7	8	13	49	13
Total	36	51	45	33	34	51	....	17
From 8 to 14 miles.								
January	30*	26	24	22	27	24	153	41
April	16	15	16	17	11	17	92	26
July	28	20	24	25	21	22	140	38
October	27	27	17	23	20	22	136	37
Total	101	88	81	87	79	85	....	35
From 15 to 20 miles.								
January	12*	15	15	19	15	17	93	25
April	17	12	14	18	19	15	95	26
July	6	13	14	11	16	16	76	20
October	13	17	20	13	13	16	93	25
Total	48	57	63	65	63	64	....	24

*January, 1890, at old office.

TABLE XL.—*Wind movement, etc.*—Continued.

(Above 20 miles.)

Month.	11 to midnight.	3 to 4 a. m.	7 to 8 a. m.	11 to noon.	3 to 4 p. m.	7 to 8 p. m.	Total.	Per cent.
January.......	8*	7	7	9	9	5	45	12
April..........	22	27	23	22	27	21	142	39
July..........	14	13	11	15	13	9	75	20
October........	15	13	16	19	21	11	95	25
Total......	59	60	57	65	70	46	....	24

* January, 1890, at old office.

MAXIMUM VELOCITIES OF WIND.

Table XLI gives the occurrence of winds above 35 miles per hour from 1877 to January, 1890, and of 40 miles per hour since the latter date. It will be seen that since 1887 the anemometer exposure has made a great increase in these velocities.

TABLE XLI.—*Dates on which the maximum velocity of the wind was 35 miles per hour (40 miles since February,* 1890).

Year.	Date.	Year.	Date.	Year.	Date.	Year.	Date.
1877..........	Apr. 1	1888..........	Mar. 22	1890..........	Feb. 28	1890..........	June 3
1877..........	June 25	1888..........	Apr. 13	1890..........	Mar. 14	1890..........	June 4
1878..........	Mar. 5	1888..........	May 3	1890..........	Mar. 25	1890..........	June 5
1878..........	Apr. 10	1888..........	May 4	1890..........	Mar. 26	1890..........	June 6
1878..........	July 3	1888..........	May 28	1890..........	Mar. 27	1890..........	June 14
1879..........	None.	1888..........	July 11	1890..........	Mar. 28	1890..........	June 22
1880..........	Apr. 15	1888..........	July 12	1890..........	Apr. 3	1890..........	June 27
1880..........	Apr. 19	1888..........	July 31	1890..........	Apr. 4	1890..........	June 29
1880..........	June 6	1888..........	Aug. 2	1890..........	Apr. 8	1890..........	July 4
1880..........	June 7	1888..........	Aug. 21	1890..........	Apr. 9	1890..........	July 14
1881..........	Mar. 19	1888..........	Aug. 31	1890..........	Apr. 11	1890..........	July 30
1882..........	None.	1888..........	Nov. 6	1890..........	Apr. 12	1890..........	Aug. 3
1883..........	None.	1888..........	Nov. 8	1890..........	Apr. 13	1890..........	Aug. 8
1884..........	Apr. 27	1888..........	Nov. 9	1890..........	Apr. 14	1890..........	Sept. 19
1884..........	Oct. 8	1888..........	Dec. 4	1890..........	Apr. 15	1890..........	Sept. 24
1885..........	None.	1888..........	Dec. 26	1890..........	Apr. 24	1890..........	Sept. 27
1886..........	Oct. 14	1888..........	Dec. 27	1890..........	Apr. 26	1800..........	Oct. 13
1887..........	Feb. 26	1889..........	Jan. 9	1890..........	Apr. 29	1890..........	Oct. 14
1887..........	Mar. 2	1889..........	Jan. 17	1890..........	Apr. 30	1890..........	Oct. 15
1887..........	Apr. 4	1889..........	Mar. 18	1890..........	May 1	1890..........	Oct. 18
1887..........	Apr. 23	1889..........	Apr. 24	1890..........	May 3	1890..........	Oct. 19
1887..........	May 2	1889..........	May 30	1890..........	May 8	1890..........	Nov. 1
1887..........	Sept. 27	1880..........	May 31	1890..........	May 9	1890..........	Nov. 5
1887..........	Oct. 3	1889..........	July 28	1890..........	May 10	1890..........	Nov. 8
1887..........	Oct. 6	1889..........	Nov. 27	1890..........	May 15	1890..........	Nov. 9
1887..........	Nov. 18	1889..........	Nov. 28	1890..........	May 16	1890..........	Nov. 13
1887..........	Nov. 19	1889..........	Dec. 29	1890..........	May 17	1890..........	Dec. 13
1888..........	Feb. 13	1890..........	Jan. 8	1890..........	May 18	1890..........	Dec. 23
1888..........	Feb. 14	1090..........	Feb. 4	1890..........	May 21	1890..........	Deb. 27
1888..........	Feb. 20	1890..........	Feb. 5	1890..........	May 22	1890..........	Dec. 28
1888..........	Feb. 26	1890..........	Feb. 8	1890..........	May 24		
1888..........	Mar. 21	1890..........	Feb. 19	1890..........	May 28		

WIND DIRECTION.

There has been given already a discussion of wind direction as affected by the lake. In Table XLII are given the mean wind directions for each month for 20 years. The general tendency of the wind from a westerly quarter is shown quite plainly in the colder months, but in the warmer months the mean direction is quite irregular owing to the fewness of the observations in part, and to the difference in the exposure in wind vanes in greater part.

TABLE XLII.—*Wind direction at Chicago, by years.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	°	°	°	°	°	°	°	°	°	°	°	°
1872	s 67 w	n 52 w	n 67 w	s 8 w	s 24 w	s 11 w	n 78 w	s 77 w	s 22 w	s 83 w	s 39 w	s 66 w
1873	s 37 w	s 51 w	s 65 w	n 2 w	n 47 e	s 69 e	n 85 w	n 49 e	s 71 w	s 62 w	s 75 w	s 54 w
1874	s 53 w	s 54 w	n 76 w	n 1 w	n 74 e	s 8 w	s 22 e	n 20 e	s 17 w	n 81 w	s 64 w	s 83 w
1875	s 82 e	s 58 e	s 89 w	n 15 e	s 26 w	n 46 w	n 56 w	s 16 e	s 49 e	s 72 e	s 21 e	s 51 e
1876	s 50 w	s 44 w	n 60 w	s 6 e	n	s 35 w	n 10 e	s 50 e	n 2 e	s 42 w	s 55 w	s 65 w
1877	s 43 w	n 62 w	n 38 w	n 22 e	s 64 e	s 56 w	s 33 w	s 76 e	s 24 e	n 59 e	s 75 e	s 18 e
1878	s 50 w	n 74 e	s 60 e	n 54 e	s 28 e	s 45 e	n 86 e	s 34 e	s 48 w	s 59 w	n 79 w	s 62 w
1879	s 80 w	s 79 w	s 64 w	n 40 e	n 80 e	n 88 e	s 2 w	s 9 e	s 58 w	s 33 w	s 61 w	s 46 w
1880	s 63 w	s 62 w	s 34 w	s 34 w	s 7 w	s 28 w	s 31 w	s 56 e	s 32 w	s 44 w	s 63 w	n 77 w
1881	n 68 w	s 1 w	n 36 w	n 43 w	n 30 e	n 7 w	n 23 w	s 80 e	s 27 w	s 25 e	s 59 w	s 73 w
1882	s 65 w	s 63 w	s 83 w	n 39 e	n 64 e	n 31 w	s 73 w	n 48 e	s 52 e	s 17 e	s 33 w	s 54 w
1883	s 59 w	s 64 w	n 46 w	n 89 e	n 40 e	s 85 w	n 42 w	n 5 w	n 41 e	n 48 e	s 57 w	s 73 w
1884	s 73 w	n 77 w	n 74 w	n 27 e	s 9 e	n 28 e	n 12 w	s 61 e	s 13 w	s 49 w	s 79 w	s 55 w.
1885	s 58 w	s 62 w	n 77 w	n 66 e	n 15 e	s 32 e	s 82 e	n 34 e	s 6 e	n 75 w	s 81 w	s 46 w
1886	s 56 w	s 40 w	n 66 w	n 14 w	n 51 e	n 75 e	n 56 e	s 76 e	s 5 e	s 5 w	s 55 w	s 41 w
1887	s 79 w	s 57 w	n 23 w	s 16 w	n 65 e	n 81 e	s 60 e	n 57 e	s 75 e	s 70 w	s 72 w	s 51 w
1888	n 83 w	s 59 w	n 13 w	n 9 w	s 82 e	s 40 e	n 79 e	n 84 w	s 6 w	s 82 w	n 79 w	s 77 w
1889	s 69 w	s 88 w	n 3 e	n 78 e	n 84 w	n 68 w	s 79 e	s 29 w	s 34 w	n 12 e	n 80 w	s 42 w
1890	s 69 w	s 87 w	n 28 w	s 77 e	s 45 w	s 25 e	s 61 e	s 76 e	s 74 e	n 46 w	s 85 w	n 87 w
1891	s 78 w	s 69 w	n 67 e	n 85 e	n 65 e	s 61 e	s 4 w	s 45 w	s 22 w	s 63 w	s 85 w	s 71 w
Mean for 15 years	s 61 w	s 51 w	n 69 w	n 2[illegible] e	s 85 e	s 19 w	s 43 w	s 71 e	s 21 w	s 36 w	s 59 w	s 59 w

NOTE.—Mean yearly direction, s. 53° w.

DEW-POINT AND RELATIVE HUMIDITY.

During the years 1882–1886 observations were made 5 times each day, at 6.10 and 10.10 a. m., and 2.10, 6.10, and 10.10 p. m. (Chicago time).. Table XLIII gives these observations for dew-point and relative humidity, which never before have been worked up. Fig. 21 shows the departure from the mean by hours and months. In the colder months the dew-point reaches a minimum at 6 a. m. and a maximum at 3 p. m., while in the warmer months there is but little variation.

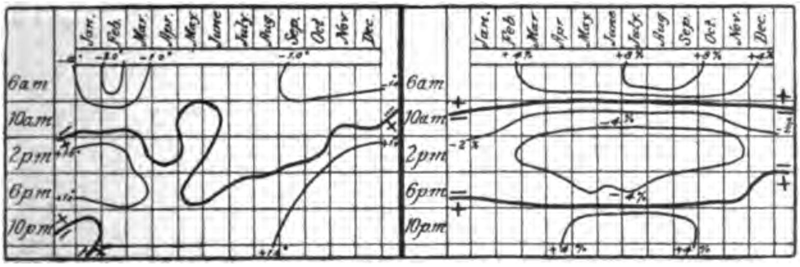


FIG. 21.—*Dew-point and relative humidity departures.*

[illegible]

	[illegible]					[illegible]					[illegible]					[illegible]				
	6.	10.	2.	6.	10.	6.	10.	2.	6.	10.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
	21.2	21.7	26.8	24.8	23.6	29.2	30.8	33.3	33.1	31.4	30.8	31.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	8.7	9.2	10.0	10.1	8.3	11.2	14.2	15.2	15.6	14.7	18.1	17.7	18.3	19.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	9.0	10.6	13.9	10.9	8.6	16.9	19.2	21.3	20.1	18.5	22.7	24.3	26.0	26.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1885	9.2	9.4	12.4	13.2	11.7	7.1	10.0	15.5	13.4	12.0	20.8	22.3	24.6	24.3	23.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1886	15.0	17.7	17.8	19.5	18.5	19.4	21.9	21.5	23.9	23.2	28.3	29.2	29.5	31.7	31.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean dew-point.	12.6	13.7	16.2	15.7	14.1	16.8	19.2	21.4	21.2	20.0	24.1	24.9	26.3	27.2	26.4	36.6	37.0	37.0	37.4	37.5
Grains per cubic foot	0.940	0.986	1.100	1.076	1.003	1.128	1.254	1.379	1.367	1.298	1.547	1.599	1.695	1.759	1.702	2.525	2.563	2.563	2.601	2.611

	May.					June.					July.					August.				
1882	41.8	42.3	41.9	42.2	42.2	55.5	56.5	55.0	56.1	56.5	56.8	56.1	56.0	56.8	58.1	63.1	62.9	62.5	64.1	64.0
1883	42.1	43.1	41.2	40.8	41.9	54.3	55.2	55.4	55.6	55.4	58.9	59.4	60.2	60.8	60.9	55.8	56.0	56.9	57.1	57.7
1884	43.9	43.5	44.8	43.8	44.5	55.0	55.7	56.0	54.7	56.5	58.2	57.9	58.1	58.9	59.0	57.5	56.9	56.5	58.1	58.1
1885	42.0	42.6	42.5	42.4	44.2	55.0	55.8	54.7	54.4	55.7	62.8	63.8	63.6	64.3	64.5	58.2	58.7	57.2	58.3	59.9
1886	46.3	47.2	47.6	46.3	48.4	56.0	56.5	56.5	56.5	56.9	59.6	60.6	60.3	60.7	61.6	62.0	62.1	62.4	62.5	63.2
Mean dew-point.	43.4	43.7	43.6	43.1	44.2	55.2	55.9	55.5	55.5	56.2	59.3	59.6	59.6	60.3	60.8	59.3	59.3	59.1	60.0	60.6
Grains per cubic foot	3.236	3.271	3.259	3.201	3.330	4.894	5.011	4.944	4.944	5.063	5.623	5.680	5.680	5.785	5.933	5.623	5.623	5.585	5.756	5.874

	September.					October.					November.					December.				
1881	56.7	58.8	58.7	60.4	58.9	48.3	49.2	49.2	50.0	49.8	32.2	33.3	34.2	33.8	32.4	30.8	31.0	32.9	32.8	31.6
1882	54.0	53.8	54.6	55.4	55.9	46.7	49.2	49.0	51.5	50.1	33.9	34.1	35.1	35.1	34.3	17.5	17.5	20.2	20.6	19.1
1883	49.2	49.6	49.1	50.0	50.7	42.0	42.1	42.2	42.6	42.5	28.8	30.0	32.0	31.1	30.7	19.4	21.8	24.0	23.3	21.1
1884	56.4	57.2	56.6	58.2	58.8	44.6	46.0	46.7	48.3	46.5	30.4	32.7	33.7	34.2	32.2	21.0	22.6	24.1	24.6	23.2
1885	52.6	52.8	54.1	54.3	55.4	41.3	41.8	42.5	43.6	42.9	33.3	35.1	35.3	36.2	34.5	24.5	25.7	27.6	27.5	25.7
Mean dew-point.	53.8	54.4	54.6	55.7	55.9	44.6	45.7	45.9	47.2	46.4	31.7	33.0	34.1	34.1	32.8	22.6	23.7	25.8	25.8	24.1
Grains per cubic foot	4.664	4.762	4.794	4.978	5.011	3.378	3.513	3.520	3.653	3.602	2.102	2.208	2.301	2.301	2.192	1.452	1.521	1.660	1.660	1.547

RELATIVE HUMIDITY.

	January.					February.					March.					April.				
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
1882	83.2	79.3	83.5	80.5	82.8	82.3	75.8	70.9	75.6	77.9	84.6	77.5	74.5	77.6	81.2	77.7	65.5	64.7	69.4	74.4
1883	74.5	71.3	67.4	73.6	73.7	73.2	67.0	61.6	66.5	70.1	66.2	54.6	51.6	56.6	60.6	70.9	60.7	57.6	61.1	63.8
1884	71.5	68.0	67.3	66.9	66.9	71.7	71.0	68.8	67.9	67.9	72.5	65.8	62.7	68.2	67.9	74.6	63.0	58.9	62.0	69.2
1885	78.3	71.2	67.3	72.8	76.6	78.8	73.2	80.1	77.4	80.0	78.6	72.4	71.9	73.1	75.1	80.8	71.2	70.1	74.8	78.4
1886	83.9	86.0	79.2	85.5	88.0	80.6	80.1	68.6	78.4	80.9	83.7	75.7	69.1	78.9	81.2	86.9	79.6	75.9	80.7	85.5
Mean.	78.3	75.2	72.9	75.9	77.6	77.3	73.4	70.0	73.2	75.4	77.1	69.2	66.0	70.9	73.4	78.2	68.0	65.4	69.6	74.3

	May.					June.					July.					August.				
1882	76.1	67.9	63.6	66.7	74.4	82.2	72.6	68.9	70.4	80.8	74.1	61.7	59.0	60.3	72.2	84.9	72.3	66.4	76.0	80.6
1883	74.7	65.3	61.2	62.9	72.0	77.5	69.6	67.2	69.9	77.1	76.0	64.5	59.1	61.6	73.6	73.8	62.6	59.4	62.4	71.3
1884	71.9	59.8	57.1	58.1	67.6	75.9	68.6	65.5	70.5	77.7	76.2	64.2	61.0	63.5	72.6	78.2	62.2	56.6	63.6	70.0
1885	75.7	65.5	62.8	65.3	74.1	77.5	66.3	59.6	62.9	75.4	80.3	70.0	64.8	68.3	77.4	79.6	70.3	62.8	67.3	75.6
1886	77.1	68.5	64.7	63.5	73.7	76.9	69.2	65.5	66.9	75.6	74.9	67.1	61.5	63.6	73.8	79.4	68.1	64.2	67.8	74.9
Mean.	75.1	65.4	61.9	63.3	72.4	78.0	69.3	65.3	68.1	77.3	76.3	65.5	61.1	63.5	73.9	79.2	67.1	61.9	67.4	74.5

	September.					October.					November.					December.				
1881	75.6	66.0	60.0	69.5	73.0	83.8	75.4	70.6	78.2	82.7	81.2	77.1	71.7	78.1	78.0	86.0	79.0	76.7	80.4	82.5
1882	79.1	64.4	60.7	66.4	73.5	81.2	72.7	66.9	77.5	81.2	80.2	73.8	71.0	74.4	76.3	77.3	70.2	70.5	75.0	76.1
1883	76.4	62.7	59.5	66.6	71.3	77.8	69.7	65.6	68.7	71.9	71.9	64.9	60.9	62.6	65.9	73.8	70.0	67.4	70.6	69.5
1884	77.4	64.5	57.4	63.7	71.1	77.1	65.6	60.0	69.3	70.9	81.6	75.3	68.1	75.2	76.3	82.8	79.9	75.6	81.2	80.4
1885	76.8	66.1	63.5	68.6	75.1	80.8	68.9	64.4	70.6	75.3	79.8	76.3	71.9	75.6	76.5	82.5	80.3	79.1	82.7	82.0
Mean.	77.1	64.7	60.2	67.0	72.8	80.1	70.5	65.5	72.9	76.4	78.9	73.5	68.7	73.2	74.6	80.5	75.9	73.9	78.0	78.1

The relative humidity shows a maximum at 6 a. m. in all the months and a minimum at 2 p. m.

The average monthly relative humidity from 1886 to 1891 is given in Table XLIV. There is a maximum in January and a minimum in July with a secondary maximum well marked in June, due possibly to the prevalence of lake winds at the time of observation.

TABLE XLIV.—*Mean relative humidity of Chicago.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
	%	%	%	%	%	%	%	%	%	%	%	%	%
1886	84	77	78	83	72	73	70	73	71	71	77	76	75
1887	79	83	75	62	68	70	67	68	72	70	71	78	72
1888	75	76	72	62	70	66	68	66	66	69	78	81	71
1889	83	83	76	75	71	79	73	66	69	70	83	76	75
1890	81	82	74	72	71	73	64	74	76	82	73	76	75
1891	82	81	84	75	67	81	70	74	66	67	79	77	75
Mean.........	80·7	80·3	76·5	71·5	69·8	73·7	68·7	70·2	70·0	71·5	76·8	77·3	73·9

CLOUDS.

Table XLV gives the average cloudiness on a scale 0–10 for 18 years. Observations were made three times each day, except only twice daily from July–December, 1888. The maximum cloudiness is in December, and the minimum in July and August. The latter interesting fact may be explained, in part at least, by the occurrence of cool lake winds which have their moisture dissipated by the warm air over the land surface. No such minimum as this is to be found at any other station in the interior near Chicago.

TABLE XLV.—*Average cloudiness,* 0 *to* 10.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
1871	6·5	4·8	5·2	5·8	5·0	4·7	3·8	3·2	3·5	......	6·5	5·0	......
1872	6·0	5·0	5·2	4·7	4·7	4·5	3·7	4·0	4·0	3·0	5·5	5·7	4·7
1873	7·5	5·2	5·5	7·2	6·2	4·5	4·2	4·0	5·0	5·5	6·2	6·0	5·6
1874	6·0	6·2	5·2	5·2	4·5	5·0	3·0	3·7	4·2	5·0	5·0	6·2	4·9
1875	4·8	5·0	5·7	5·0	3·5	5·8	4·8	3·7	4·8	6·0	6·3	6·0	5·1
1876	5·8	4·5	6·5	4·8	4·2	6·2	3·8	3·2	5·2	4·8	8·0	5·5	5·2
1877	5·0	4·2	5·7	5·0	3·5	4·5	3·0	4·0	3·5	6·5	7·2	6·2	4·9
1878	6·2	6·5	6·2	6·0	4·7	5·0	5·0	3·7	4·5	5·5	5·2	6·0	5·4
1879	5·0	6·0	5·7	3·5	4·5	4·5	3·5	4·2	4·2	4·7	5·7	6·5	4·8
1880	5·7	5·5	5·5	5·2	4·0	4·7	4·5	2·2	4·5	4·7	5·5	6·5	4·9
1881	5·7	6·2	6·5	5·0	3·0	5·5	3·6	3·4	4·3	5·8	5·7	5·5	5·0
1882	5·3	4·9	6·3	6·1	6·1	5·9	4·3	4·9	3·8	4·6	6·6	5·6	5·4
1883	5·6	5·0	5·0	4·9	6·7	5·4	4·4	3·5	3·9	6·9	4·4	5·1	5·1
1884	5·4	7·1	6·5	5·9	4·6	5·0	4·7	3·5	3·7	4·2	4·8	7·4	5·2
1885	4·8	5·1	5·7	6·1	4·9	4·5	3·8	4·6	4·5	5·5	6·7	5·4	5·1
1886	6·4	5·6	5·7	5·0	4·2	4·0	2·6	4·5	4·6	3·8	5·2	5·7	4·8
1887	6·4	6·8	5·2	4·6	3·8	4·2	3·0	4·1	5·9	4·9	5·2	7·5	5·1
1888	6·1	4·9	6·6	4·1	6·0	4·7	4·6	4·3	3·0	4·2	5·0	5·6	4·9
Mean........	5·7	5·5	5·8	5·2	4·7	4·9	3·9	3·9	4·3	5·0	5·8	6·0	5·1

Table XLVI gives the mean cloudiness at the hours 6 and 10 a. m., and 2, 6, and 10 p. m., during the years 1882–1886. Here we find a marked minimum in the graphic presentation of this table at 10 p. m. (Fig. 22), while there is a maximum in all the months at 2 p. m., or during the hottest part of the day. At first sight this appears to be a contradiction to the July and August minimum occurring at the hottest part of the year, but this disappears if we consider that that is produced by the lake winds, while here the maximum may be due to a slight upward tendency which would carry the warm air into a cooler region where its moisture would be condensed.

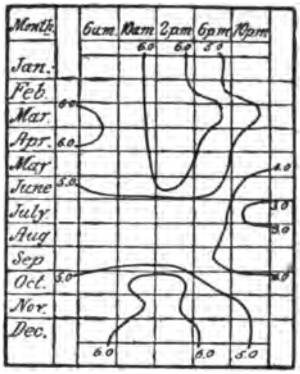


FIG. 22.—*Diurnal and monthly variation of cloudiness.*

TABLE XLVI.—*Mean cloudiness, Chicago.*

Year.	January.					February.					March.					April.				
	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.
1882...........	4.1	5.6	6.7	6.5	5.2	5.1	5.1	5.7	3.7	3.8	6.6	6.9	6.4	6.9	5.8	6.4	5.3	6.7	4.7	5.2
1883...........	5.9	5.8	6.3	5.2	4.5	4.1	5.2	5.6	4.2	5.3	5.2	5.5	5.7	5.8	4.1	6.0	4.7	5.2	4.2	3.5
1884...........	6.2	5.8	6.1	4.3	3.9	6.6	6.2	8.1	7.2	6.5	6.6	5.8	6.9	6.0	6.1	5.9	5.4	6.9	6.4	4.8
1885...........	4.2	5.0	5.7	3.9	4.6	4.5	5.6	5.7	4.8	5.1	5.3	4.4	6.3	6.7	5.4	6.2	6.4	6.7	6.5	5.5
1886...........	6.1	7.0	7.1	5.5	6.1	6.6	6.8	6.2	5.2	3.9	6.1	6.2	5.8	7.1	5.2	5.7	5.8	5.5	6.6	3.7
Mean..	5.3	5.8	6.4	5.1	4.9	5.4	5.8	6.3	5.0	4.9	6.0	5.8	6.2	6.5	5.3	6.0	5.5	6.2	5.7	4.5

Year.	May.					June.					July.					August.				
	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.
1882...........	5.8	5.6	6.7	5.4	5.7	6.4	5.8	6.7	5.4	4.7	3.9	4.1	4.8	4.7	4.1	5.6	5.4	5.4	5.8	3.6
1883...........	7.5	6.4	7.3	6.6	5.4	5.4	6.0	7.2	6.7	3.7	5.2	4.6	4.8	4.7	3.2	2.9	3.7	4.5	3.9	3.0
1884...........	4.8	5.3	5.6	5.9	3.3	6.1	5.2	5.5	5.4	3.3	5.3	5.1	6.2	5.9	2.5	4.2	4.5	4.3	3.7	2.1
1885...........	5.2	4.7	5.1	5.6	4.4	4.8	5.0	5.3	4.1	3.3	4.3	4.2	4.6	4.9	2.5	5.7	5.4	4.7	4.6	3.4
1886...........	4.3	4.6	5.6	5.2	2.8	3.9	4.5	5.1	4.6	3.1	3.4	3.2	3.2	2.8	1.3	5.2	4.6	4.7	4.5	3.5
Mean..	5.5	5.3	6.1	5.7	4.3	5.3	5.3	6.0	5.2	3.6	4.4	4.2	4.7	4.6	2.7	4.7	4.7	4.7	4.5	3.1

Year.	September.					October.					November.					December.				
	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.	6.	10.	14.	18.	22.
1881...........	5.0	4.7	5.0	4.0	2.9	5.9	7.5	6.1	5.6	5.2	5.6	6.0	5.9	6.1	5.6	5.1	6.1	6.7	5.3	4.7
1882...........	5.0	4.3	4.1	3.6	2.3	4.5	5.0	5.2	3.9	4.0	6.6	7.3	7.3	6.3	6.0	5.7	5.6	6.0	6.2	5.0
1883...........	3.9	3.9	4.8	4.3	2.9	7.0	7.3	7.4	7.3	6.4	4.6	4.0	5.0	5.0	3.5	4.8	6.5	6.7	4.4	3.7
1884...........	3.9	3.6	3.6	2.7	3.6	4.4	4.2	5.1	2.6	3.1	5.7	4.9	4.9	4.8	3.9	8.1	7.5	7.2	6.7	6.9
1885...........	4.7	4.4	4.8	5.2	4.0	5.4	6.0	7.1	5.0	4.0	6.8	6.2	7.1	6.8	6.1	4.7	6.3	6.7	5.8	4.9
Mean..	4.5	4.2	4.5	4.0	3.1	5.4	6.0	6.2	4.9	4.5	5.9	5.7	6.0	5.8	5.0	5.7	6.4	6.7	5.7	5.0

CLEAR, FAIR, CLOUDY, AND RAINY DAYS.

A rainy day is one on which at least .01 inch of rain or more falls. Table XLVII shows the prevalence of such days from 1871–1891.

From the summary at the close of this table we see that the maximum of clear days is in July with a minimum in January; of fair days, these conditions occur in August and November, respectively; of cloudy days, in November and July; and of rainy days, in December and September.

Table XLVII.—*Number of clear, fair, cloudy, and rainy days at Chicago from* 1871 *to* 1891.

Year.	January.				February.				March.			
	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.
1871	7	7	17	12	15	4	9	6	11	13	7	11
1872	4	17	10	7	9	10	10	6	8	13	10	9
1873	3	9	19	13	9	11	8	4	7	15	9	13
1874	7	11	13	14	5	12	11	13	9	12	10	9
1875	7	16	8	13	9	10	9	9	11	6	14	15
1876	10	7	14	11	13	9	7	9	5	9	17	16
1877	11	10	10	8	9	16	3	2	9	13	9	17
1878	5	12	14	15	5	10	13	15	5	16	10	16
1879	8	14	9	9	4	14	10	15	5	15	11	16
1880	7	16	8	14	7	12	19	12	9	15	7	10
1881	7	9	15	10	6	9	13	16	5	10	16	12
1882	8	17	6	12	10	8	10	11	5	13	13	14
1883	8	13	10	16	7	15	6	12	11	12	8	8
1884	9	13	9	13	4	11	14	16	4	11	16	15
1885	10	13	8	11	10	9	9	11	6	17	8	8
1886	4	15	12	19	6	15	7	9	7	11	13	9
1887	3	16	12	13	5	6	17	17	9	13	9	6
1888	6	15	10	12	11	12	6	9	7	11	13	12
1889	10	8	13	5	4	13	11	13	9	15	7	5
1890	7	13	11	14	7	6	15	12	9	13	9	15
1891	3	9	19	11	10	8	10	12	2	12	17	15
Sum	144	260	247	252	165	220	208	229	153	265	233	251
Mean	6.9	12.4	11.8	12.0	7.9	10.5	9.9	10.9	7.3	12.6	11.1	12.0

Year.	April.				May.				June.			
	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.
1871	5	15	10	12	16	3	12	11	15	9	6	14
1872	......	......	......	......	9	14	8	9	9	16	5	9
1873	5	8	17	17	6	14	11	16	6	17	7	6
1874	9	12	9	8	12	9	10	9	9	14	7	10
1875	8	13	9	4	14	10	7	14	6	13	11	15
1876	11	10	9	8	10	15	6	14	4	11	15	17
1877	12	8	10	11	17	9	5	5	6	19	5	15
1878	7	11	12	13	9	12	10	14	8	15	7	12
1879	14	10	6	10	15	8	8	8	10	11	9	12
1880	7	14	9	17	16	8	7	11	8	14	8	13
1881	7	14	9	12	16	11	4	10	7	15	8	14
1882	5	15	10	12	6	12	13	14	5	16	9	14
1883	9	15	6	11	4	14	13	17	7	14	9	13
1884	9	9	12	9	9	17	5	10	9	13	8	6
1885	3	19	8	16	11	13	7	11	9	15	6	11
1886	8	13	9	10	12	14	5	10	10	18	2	8
1887	5	22	3	5	15	8	8	9	12	13	5	7
1888	12	13	5	10	7	10	14	16	8	17	5	8
1889	10	9	11	8	4	15	12	14	1	13	16	12
1890	13	9	8	12	8	10	13	16	8	17	5	14
1891	10	10	10	15	14	10	7	7	7	12	11	11
Sum	169	249	182	220	230	236	185	245	164	302	164	241
Mean	8.4	12.4	9.1	11.0	11.0	11.2	8.8	11.7	7.8	14.4	7.8	11.5

Table XLVII.—*Number of clear, fair, cloudy, and rainy days, etc.*—Continued.

Year	July.				August.				September.			
	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.
1871	14	10	7	8	16	10	5	8	16	9	5	4
1872	17	10	4	7	13	10	8	11	10	17	3	12
1873	10	15	6	15	11	14	6	10	9	13	8	8
1874	15	14	2	5	15	12	4	7	14	9	7	9
1875	10	13	8	15	12	16	3	10	8	13	9	8
1876	12	15	4	10	14	14	3	7	9	8	13	11
1877	18	11	2	8	11	13	7	1	11	13	6	7
1878	7	15	9	10	12	16	3	15	11	13	6	10
1879	15	12	4	7	10	16	5	7	8	17	5	12
1880	12	18	1	9	13	11	7	14	13	9	8	11
1881	17	8	6	10	15	13	3	4	8	16	6	13
1882	13	9	9	13	9	17	5	16	13	14	3	6
1883	13	11	7	11	16	10	5	4	14	12	4	8
1884	5	25	1	12	15	12	4	9	15	9	6	8
1885	9	20	2	13	8	18	5	13	13	8	9	9
1886	18	11	2	6	8	19	4	11	11	11	8	13
1887	18	11	2	10	14	10	7	9	7	11	12	14
1888	11	8	12	11	9	11	11	9	13	9	8	6
1889	14	8	9	12	15	11	5	7	8	11	11	7
1890	13	17	1	5	12	10	9	10	9	12	9	7
1891	13	13	5	8	10	14	7	10	20	9	1	4
Sum	274	274	103	205	258	277	116	192	240	243	147	187
Mean	13.0	13.0	4.9	9.8	12.3	13.2	5.5	9.1	11.4	11.6	7.0	8.9

Year.	October.				November.				December.			
	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.	Clear.	Fair.	Cloudy.	Rainy.
1871	......	......	......	......	8	7	15	12	14	7	10	10
1872	18	10	3	3	8	10	12	11	5	14	12	9
1873	8	13	10	12	4	9	17	11	8	9	14	10
1874	10	13	8	9	10	10	10	12	7	14	10	7
1875	8	9	14	13	5	13	12	10	5	11	15	13
1876	13	9	9	9	2	6	22	12	5	13	13	13
1877	1	17	13	14	3	6	21	14	6	8	17	14
1878	7	14	10	13	8	15	7	10	9	9	13	19
1879	5	20	6	10	4	12	14	12	3	14	14	17
1880	11	11	9	10	12	7	11	9	6	10	15	13
1881	6	12	13	17	7	13	10	12	10	11	10	9
1882	11	14	6	12	3	14	13	14	9	10	12	14
1883	6	8	17	19	14	7	9	9	9	15	7	11
1884	14	11	6	10	9	14	7	9	4	9	18	18
1885	8	13	10	11	4	13	13	12	8	15	8	15
1886	19	4	8	7	10	10	10	10	8	12	11	12
1887	12	10	9	8	11	8	11	7	4	7	20	13
1888	9	11	11	11	8	6	16	11	9	5	17	9
1889	14	7	10	7	5	9	16	17	10	9	12	10
1890	4	9	18	15	11	7	12	8	10	10	11	8
1891	13	11	7	5	6	5	19	11	11	9	11	9
Sum	197	226	197	215	152	201	277	233	160	221	270	253
Mean	9.8	11.3	9.8	10.8	7.2	9.6	14.1	11.1	7.6	10.4	12.9	12.0

SUMMARY.

Month.	Clear.	Fair.	Cloudy.	Rainy.	Month.	Clear.	Fair.	Cloudy.	Rainy.
January	144	260	247	252	July	274	274	103	205
February	165	220	207	229	August	258	277	116	192
March	153	265	233	251	September	240	243	147	187
April	169	249	182	220	October	197	226	197	215
May	230	236	185	245	November	152	201	277	233
June	164	302	164	241	December	160	221	270	253

In order to determine whether we have to deal with a lake influence in these conditions of clouds and rain, I have instituted a comparison between the same data at the three lake stations, Chicago, Milwaukee, and Grand Haven. These results are given in Table XLVIII and show that in the main it is the lake that causes these conditions on all sides. The cloudiness at Grand Haven during the colder months is phenomenal.

TABLE XLVIII.—*Clear, fair, cloudy, and rainy days at Chicago, Milwaukee, and Grand Haven*, 1871-1890.

Month.	Clear.			Fair.			Cloudy.			Rainy.		
	Chicago.	Milwaukee.	Grand Haven.	Chicago.	Milwaukee.	Grand Haven.	Chicago.	Milwaukee.	Grand Haven.	Chicago.	Milwaukee.	Grand Haven.
January	7.0	5.6	1.5	13.3	14.5	8.2	10.7	10.9	21.3	12.2	13.1	20.0
February	7.9	5.9	4.0	11.2	12.4	10.2	9.2	10.0	14.1	10.7	10.1	13.4
March	6.9	6.7	5.0	12.9	13.5	13.3	11.2	10.8	12.7	12.1	12.1	13.7
April	7.9	6.7	8.0	12.9	13.7	12.6	9.2	9.6	9.4	11.3	10.7	10.5
May	11.0	9.3	11.2	11.7	13.2	12.3	8.3	8.5	7.5	11.6	11.4	11.5
June	8.0	7.3	9.7	14.7	16.2	13.8	7.3	6.5	6.5	11.3	11.7	9.1
July	12.7	10.2	13.4	13.2	16.2	13.5	5.1	4.6	4.1	10.0	10.8	8.6
August	12.1	10.1	13.0	13.7	14.9	13.2	5.2	6.0	4.8	9.7	9.2	9.1
September	11.2	9.0	10.2	11.8	13.8	12.4	7.0	7.2	7.4	9.4	10.7	10.8
October	9.9	7.3	7.9	11.8	13.1	10.4	9.3	10.6	12.7	10.4	9.9	12.3
November	7.1	5.4	3.6	10.1	11.8	9.2	12.8	12.8	17.2	11.1	10.3	14.5
December	6.6	5.4	1.4	11.2	12.5	7.5	13.2	13.1	22.1	12.6	18.5	17.2

DIRECTIONS OF WINDS AND CLOUDS.

It has been a mooted question in Europe as to the relative directions of the winds and clouds. In this country it has been found that the two have the same direction, in general, or, when they differ, the clouds have a tendency to move in the general upper current to the east. It was thought of some interest to inquire whether this law holds good at Chicago or whether the lake caused a divergence.

Table XLIX exhibits a summary of observations for the 14 years, 1878–1891. We see that during 56 per cent. of the observations the direction of the clouds was the same as that of the wind; for 24 per cent. they differed 45°; 9 per cent., 90°; 7 per cent., 135°; and 4 per cent., 180°. Or, we may say that in 80 per cent. of the cases the direction was practically the same with both. It was noted that the winds which did not follow the rule were often light and influenced by the lake.

TABLE XLIX.—*Clouds and winds, Chicago.*

SAME DIRECTION.

Month.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	Sum.	Mean
January	24	16	4	8	19	10	17	7	11	25	53	41	25	28	288	20.6
February	24	9	14	13	10	14	33	16	11	46	50	15	17	27	299	21.4
March	37	17	19	7	21	24	30	34	17	58	63	10	24	49	410	29.3
April	33	6	27	2	22	13	23	11	13	51	33	27	17	21	299	21.4
May	19	10	15	5	25	17	10	13	9	48	30	36	29	14	280	20.0
June	23	11	13	8	16	22	7	21	11	49	32	24	21	13	271	19.4
July	19	14	10	4	14	16	13	17	9	60	20	24	15	8	243	17.4
August	13	19	18	12	21	11	10	20	15	69	33	22	15	13	291	20.8
September ..	23	18	23	18	24	13	8	31	20	54	18	22	13	13	298	21.3
October......	20	19	34	26	21	21	15	25	17	55	43	36	36	21	389	27.7
November ...	19	24	16	23	25	13	15	22	15	55	47	38	35	28	375	26.8
December ...	29	9	8	10	17	27	13	7	16	62	53	39	35	21	346	24.7
Total	283	172	201	136	235	201	194	224	164	632	475	334	282	256	3,789	22.6
DIFFERING 45°.																
January	5	11	5	6	4	6	9	13	3	19	6	7	8	10	112	8.0
February	9	4	8	3	2	10	5	8	10	10	6	8	10	15	108	7.7
March	9	4	8	4	3	7	3	7	8	4	8	11	7	4	87	6.2
April	14	9	6	6	6	8	8	16	11	8	3	7	14	15	131	9.4
May	9	7	3	8	10	13	14	16	11	8	7	15	13	11	145	10.4
June	11	10	11	6	10	9	12	11	7	10	6	13	14	12	142	10.1
July	10	8	11	11	17	8	11	13	9	5	14	5	15	10	147	10.5
August	7	10	2	11	10	7	12	17	11	2	20	8	20	15	152	10.9
September ..	13	10	5	12	10	9	17	7	20	4	12	14	24	11	168	12.0
October......	9	12	5	7	9	11	13	12	19	3	11	14	15	15	155	11.1
November ...	6	3	11	3	6	13	12	19	27	0	8	11	11	25	155	11.1
December ...	9	1	5	6	8	5	10	8	9	6	11	6	11	18	113	8.1
Total	111	89	80	83	95	106	126	147	145	79	112	119	162	161	1,615	9.6
DIFFERING 90°.																
January	1	4	1	1	3	1	1	3	1	8	1	0	3	1	29	2.1
February	1	3	1	2	0	3	1	2	1	1	4	1	1	1	22	1.6
March	3	4	6	5	3	4	2	3	2	1	1	4	4	6	48	3.4
April	4	5	10	3	2	5	2	3	4	2	4	0	7	4	55	3.9
May	5	5	6	3	2	5	3	7	6	2	6	4	3	8	65	4.6
June	5	8	3	6	7	1	3	5	5	6	6	5	10	11	81	5.8
July	5	2	6	6	7	7	7	3	5	1	9	1	11	6	76	5.4
August	9	2	7	2	4	3	8	6	9	3	3	0	18	8	82	5.9
September ..	3	0	4	1	0	1	3	2	5	2	4	4	14	7	50	3.6
October......	4	3	3	2	4	4	6	8	10	0	1	0	6	4	55	3.9
November ...	6	0	3	1	5	2	4	3	14	0	1	0	6	1	46	3.3
December ...	0	0	2	0	2	0	2	2	14	0	0	0	4	10	36	2.6
Total	46	36	52	32	39	36	42	47	76	26	40	19	87	67	645	3.8
DIFFERING 135°.																
January	0	0	0	2	0	1	1	0	0	1	2	0	0	0	7	0.5
February	3	1	1	3	1	2	0	2	0	2	0	1	3	3	22	1.6
March	3	4	3	2	2	8	1	2	1	1	2	1	4	3	37	2.6
April	0	2	4	4	6	4	0	2	6	2	4	0	7	4	45	3.2
May	2	9	4	3	1	4	2	3	9	3	5	0	8	7	60	4.3
June	4	8	2	8	9	2	2	6	11	2	4	0	10	5	73	5.2
July	12	2	3	3	5	1	6	3	10	3	2	4	6	12	72	5.1
August	8	4	2	4	3	4	3	2	19	0	5	1	8	4	67	4.8
September ..	2	4	3	4	1	1	5	0	9	1	2	0	6	1	39	2.8
October......	3	0	2	2	7	2	3	0	7	0	1	1	4	1	33	2.4
November ...	1	0	0	1	2	1	1	1	1	0	2	0	1	0	11	0.8
December ...	0	0	2	1	1	0	1	0	2	0	0	1	1	3	12	0.9
Total	38	34	26	37	38	30	25	21	75	15	29	9	58	43	478	2.8

TABLE XLIX.—*Clouds and winds, Chicago*—Continued.

DIFFERING 180°.

Month.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	Sum.	Mean
January	2	2	0	0	0	1	0	1	0	1	1	0	0	0	8	0.6
February	1	0	0	1	0	0	0	0	0	1	2	0	0	0	5	0.4
March	1	3	0	1	3	2	1	0	0	3	0	1	1	3	19	1.4
April	0	0	0	2	4	3	0	0	0	1	3	1	1	0	15	1.1
May	0	2	1	1	2	3	2	1	2	0	0	1	3	0	18	1.3
June	2	2	0	3	3	0	2	5	5	5	4	1	4	10	46	3.3
July	3	4	3	0	2	3	4	0	3	1	8	1	7	3	42	3.0
August	5	5	3	1	2	0	4	5	1	1	6	0	6	4	43	3.1
September	0	2	4	0	1	0	1	3	2	3	4	1	4	1	26	1.9
October	3	2	0	1	3	2	1	0	1	0	0	0	3	0	16	1.1
November	0	0	0	0	0	0	1	0	6	0	0	0	0	0	7	0.5
December	0	0	0	0	0	0	0	1	2	1	0	0	0	0	4	0.3
Total	17	22	11	10	20	14	16	16	22	17	28	6	29	21	249	1.5

SUMMARY.

	Same.	45°.	90°.	135°.	180°.	Total.
Total	3,789	1,615	645	478	249	6,776
Per cent	56	24	9	7	4	100

OCCURRENCE OF FOGS.

Table L gives the number of fogs which have been recorded during the 17 years from 1872 to 1888, inclusive. It will be seen that by far the largest number occurred during the morning, 72 per cent., while the least number were recorded in the afternoon, 8 per cent. This was to be expected, as the relative humidity is highest in the morning and lowest in the afternoon.

TABLE L.—*Fogs at Chicago by hours.*

Year.	January.			February.			March.			April.			May.			June.			July.		
	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.
1872	0	1	0	1	0	1	0	0	0	0	0	0	....	....	....	....	....	....	2	0	0
1873	4	0	0	1	0	1	0	0	0	1	0	1	2	0	0	1	1	1	2	1	0
1874	2	0	0	1	0	0	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0
1875	1	0	0	0	0	0	5	0	0	0	0	0	1	0	1	1	3	1	1	0	1
1876	1	1	0	1	0	1	0	0	0	1	0	1	1	0	1	2	0	1	2	0	0
1877	2	0	2	1	0	2	0	0	1	1	1	2	0	0	0	0	0	0	0	0	0
1878	3	0	0	4	0	0	6	0	1	1	1	0	0	0	0	0	0	0	0	0	0
1879	6	0	1	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	1	0	0
1880	4	2	3	2	1	1	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0
1881	4	0	1	5	1	1	4	0	0	3	0	0	1	0	1	1	0	1	0	0	0
1882	4	0	1	1	1	1	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0
1883	1	0	0	1	0	0	1	0	0	....	....	....	....	....	....	....	....	....	....	....	....
1884	....	....	....	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0
1885	....	....	....	....	....	....	....	....	....	....	....	0	0	1	0	0	1	2	0	0	1
1886	1	1	1	1	3	2	0	0	0	1	0	1	2	0	0	....	....	....	....	....	....
1887	....	....	....	....	....	....	....	....	....	1	0	0	0	0	2	1	0	1	....	....	....
1888	1	2	1	4	0	2	0	0	0	1	0	1	0	0	0	1	0	0	2	0	0
Total	34	7	10	24	7	13	24	1	2	14	2	6	10	1	6	8	5	9	13	1	2

TABLE L.—*Fogs at Chicago by hours*—Continued.

Year.	August.			September.			October.			November.			December.			Annual.		
	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.	7.	15.	23.
1872	2	0	0	1	0	1	6	0	3	6	0	1	4	1	1	22	2	7
1873	1	0	0	0	0	0	2	0	0	3	0	0	1	0	0	18	2	3
1874	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	8	1	1
1875	1	0	3	1	0	1	1	0	0	0	0	0	2	2	2	14	5	9
1876	1	0	1	1	0	3	1	0	4	0	0	3	1	0	0	12	1	15
1877	3	0	0	8	0	0	17	2	1	6	1	1	5	0	3	43	4	12
1878	1	0	0	5	0	1	6	0	0	8	1	2	5	0	0	39	2	4
1879	2	0	0	0	0	0	5	0	1	1	0	0	1	0	0	22	0	2
1880	0	0	0	2	0	1	1	0	1	3	0	0	2	0	0	20	3	6
1881	0	0	0	2	0	2	2	0	0	2	0	0	1	1	0	25	2	6
1882	5	1	0	0	0	0	1	0	0	1	0	1	1	0	0	15	2	4
1883	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	0	0
1884	....	....	....	....	....	....	....	....	....	2	0	0	0	1	0	5	2	2
1885	0	0	....	....	....	....	....	....	....	2	0	0	3	0	0	5	2	3
1886	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	4	4
1887	....	....	....	3	0	0	1	0	0	3	1	1	0	0	0	9	1	4
1888	4	0	0	7	0	0	9	0	1	12	0	0	9	1	0	50	3	5
Total	20	1	4	30	0	9	54	2	11	49	3	9	35	6	6	315	36	87

In Table LI is a summation of the records by the total number of fogs in each month and year from 1872 to 1891. During the last three years there were no observations in the afternoon, and the observations at night were made about three hours earlier than previously. It will be noted that by months the colder season has much the greater amount of fog, and this is largely due to the fact that the relative humidity is much greater then, though this does not account for the superabundance of fog in September and October, or at the time the temperature gradually diminishes.

In this table there is a rather remarkable fluctuation in the amount of fog during different years. A minimum of 10 being recorded in 1874, and of 3 in 1883, while a maximum of 59 was recorded in 1877, and of 60 in 1888.

TABLE LI.—*Summary of fogs at Chicago.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1872	1	2	0	0	9	0	2	2	2	9	7	6	31
1873	4	2	0	2	2	3	3	1	0	2	3	1	23
1874	2	1	2	1	0	2	0	0	0	2	0	0	10
1875	1	0	5	0	2	5	2	4	2	1	0	6	28
1876	2	2	0	2	2	3	2	2	4	5	3	1	28
1877	4	3	1	4	0	0	0	3	8	20	8	8	59
1878	3	4	7	2	0	0	0	1	6	6	11	5	45
1879	7	0	3	3	0	0	1	2	0	6	1	1	24
1880	9	4	4	0	0	0	2	0	3	2	3	2	29
1881	5	7	4	3	2	2	0	0	4	2	2	2	33
1882	5	3	0	0	2	1	0	6	0	1	2	1	21
1883	1	1	1	0	0	0	0	0	0	0	0	0	3
1884	0	3	0	0	5	3	1	0	1	1	5	1	20
1885	0	1	1	0	4	1	2	1	0	6	5	9	30
1886	6	6	1	8	3	3	2	2	0	2	1	4	38
1887	0	2	0	1	2	5	0	0	3	1	5	0	19
1888	4	6	2	2	0	1	2	4	7	10	12	10	60
1889	8	0	6	5	0	8	1	7	2	5	4	4	50
1890	7	5	1	2	3	3	0	0	0	4	4	5	34
1891	4	4	2	0	0	7	0	1	12	6	4	6	46
Total.	73	56	40	35	27	47	20	36	54	91	80	72	631

Table LII was constructed in order to enable a comparison between the records at the three stations, Chicago, Grand Haven, and Milwaukee. It will be noticed that great irregularity occurs in the records at these stations; 1883 shows 36 cases at Grand Haven and only one at Milwaukee. A large part of these discrepancies is due to the change of observers and a lack of uniformity in making a record of fogs. The large increase of 60 in 1888 at Chicago, and of 50 in 1889, is due, in all probability, to the counting of more light fogs, for the records at the other two stations do not show any such increase in these years.

TABLE LII.—*Summary of fogs at Chicago, Grand Haven, and Milwaukee.*

Years.	Chicago.	Grand Haven.	Milwaukee.
1875	28	25	....
1876	28	36	....
1877	59	36	....
1878	45	12	....
1879	24	15	....
1880	29	2	....
1881	33	5	1
1882	21	22	1
1883	3	36	1
1884	20	30	34
1885	30	27	29
1886	38	22	25
1887	19	10	15
1888	60	26	32
1889	50	36	30

An important question arises in this connection as to the influence of smoke on fog production. It is thought, in many quarters, that fog is largely due to the abundance of carbon or smoke particles in the air, and that each fog particle has a nucleus of a smoke or dust particle. In this way the great prevalence of fog in London has been accounted for. An attempt has been made to obtain from the observations some idea of the prevalence of smoke and its gradual increase from year to year, but the records do not seem to be very complete. In 1883 smoke was reported at Chicago once; in 1884, 4 times; 1885, 18; 1886, 60; 1887, 87; in the first four months of 1888, 32 were recorded; and in the last eight only 3 records were made; in 1889 and 1890 *no* reports were made. It seems probable that it was decided not to record it, as being a purely local phenomenon and not existent outside of the immediate environment of the city. The actual amount of smoke at Chicago has increased within a year, and at the present day it is probable that more than two-thirds of the time there is a more or less dense smoke over the city. It would appear, then, as though this would be a most excellent opportunity for testing the question of the prevalence of fog concomitant with the increase of smoke.

The greatest number of fogs recorded in 20 years, with one exception, was 59 in 1877. From Table XLIX it will be seen that, with the exception of the years 1888 and 1889 (during which there were, probably, very light fogs recorded), there is no indication of an increase in the frequency of fogs during the marked increase of smoke. This is especially shown by comparing the years from 1875 to 1878 with those from 1885 to 1891. Even if we count in the abnormal years 1888 and 1889 there are still 40 fogs per year in each of these periods.

THE CAUSE OF FOG.

A study of the weather conditions prevailing at the time of and just before a fog has shown that fog is most likely to prevail in the south or south-southeast quadrant of a low area. At such a time the air is very nearly saturated with vapor, and if the wind should die down and the clouds break away there would be a strong radiation from the earth and air to the sky. The cooling brought about in this way lowers the temperature sufficiently to produce fog. In every instance examined these were the conditions, but it was not found that the direction of the wind had any marked influence, in fact, the direction of the wind is generally toward the lake during fog. From this discussion we easily see why it is that a dense fog is almost always a good indication of clearing weather.

THUNDER AND SEVERE LOCAL STORMS.

The observation of thunderstorms has been somewhat irregular, and different observers seem to have fixed their own system of making the records.

Table LIII gives a summary of the storms by months and years, and Table LIV gives them collected in two classes according to severity.

TABLE LIII.—*Thunderstorms of Chicago, by months.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
1871	......	......	1	3	4	4	5	5	......	......	......	......	22
1872	......	......	1	2	6	6	5	1	1	......	......	......	22
1873	......	......	......	1	4	2	5	......	......	......	......	......	12
1874	......	......	3	......	1	2	......	......	......	......	......	......	6
1875	......	......	2	......	......	......	2	......	......	......	......	......	4
1876	......	......	......	......	......	3	2	......	......	......	......	......	5
1877	......	......	1	3	......	5	2	......	1	......	......	......	12
1878	......	......	2	1	1	2	......	2	2	1	......	......	11
1879	......	......	2	......	2	......	1	......	......	......	......	......	5
1880	......	......	2	6	9	1	10	7	2	2	......	......	39
1881	......	......	......	......	4	6	7	1	5	2	1	......	26
1882	......	......	3	8	2	8	3	12	1	3	......	......	40
1883	......	1	......	6	3	1	5	2	......	1	2	......	21
1884	......	......	......	1	3	5	5	2	1	2	1	......	20
1885	......	......	......	......	6	5	9	8	1	......	1	......	30
1886	......	......	1	4	6	5	4	4	4	1	......	......	29
1887	1	......	......	3	4	3	8	4	2	2	......	......	27
1888	......	......	......	1	6	4	6	5	2	2	2	......	28
1889	1	......	1	3	7	6	6	4	1	1	......	1	31
1890	1	1	1	4	5	15	4	3	2	1	......	......	37
1891	......	1	1	2	2	6	4	4	2	......	......	......	22
Sum	3	3	21	48	75	89	93	64	27	18	7	1	449
Mean	0.1	0.1	1.0	2.3	3.6	4.2	4.4	3.0	1.3	0.9	0.3	0	1.77

TABLE LIV.—*Thunderstorms of Chicago, by years.*

Year.	Light.	Heavy.	Total.
1871	10	12	22
1872	13	9	22
1873	5	7	12
1874	3	3	6
1875	1	3	4
1876	4	1	5
1877	7	5	12
1878	4	7	11
1879	2	3	6
1880	32	7	39
1881	18	8	26
1882	30	10	40
1883	17	4	21
1884	13	7	20
1885	17	13	30
1886	21	8	29
1887	18	9	27
1888	20	8	28
1889	23	8	31
1890	27	10	37
1891	15	7	22
Sum	300	149	....
Mean	14.3	7.1	21.4

There seems to have been a pretty well marked minimum during 1875–1879 which was near a sun spot minimum, and the same fact has been noticed in other series of records, although in Europe it has been commonly considered that the minimum of thunderstorms comes with a maximum of sun spots. July is the month having the greater number, 4.4 in each year, and June comes next with 4.2.

Sometimes with such storms there comes a very high wind, as, for example, the wind that blew down the Young building on April 1, 1892. The severest of these local storms on record occurred on May 6, 1876; the record is that this storm moved from southwest to northeast, accompanied by rain, thunder, and lightning; bounding like a ball, it reached the ground but two or three times. The loss of property was estimated at $250,000. There have been other high winds which have wrought havoc, as, for example, the wind that wrecked some of the World's Fair buildings quite recently. These high winds, or "wind rushes," should be carefully distinguished from the tornado proper, which, so far as known, has visited Chicago but once.

DIURNAL VARIATION OF AIR PRESSURE.

On pp. 52 and 53 are given records from the barograph for the years 1890 and 1891. These are graphically presented in Fig. 23, and for purposes of comparison there are given similar curves for Atlanta, Ga., from February–August. We note the characteristic double maximum and minimum points in all the curves. The principal maximum is later in the colder than in the warmer months, and the principal minimum is correspondingly earlier at both stations. There appears also a slight tendency to a greater amplitude of the variation in the colder months than in the warmer, while at Atlanta it is just

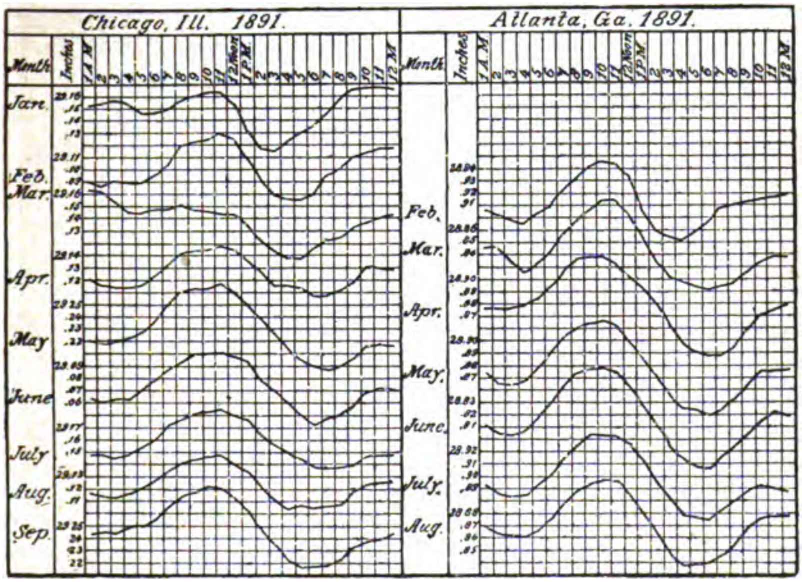


FIG 23.—*Diurnal variation of air pressure.*

the reverse. Ordinarily the increase in moisture diminishes the amplitude.

STORM WARNINGS.

It may not generally be known that the first storm warning of the Signal Service was issued from Chicago. It was as follows:

CHICAGO, *November* 8, 1870—*Noon.*

A high wind all day yesterday at Cheyenne and Omaha. A very high wind reported this morning at Omaha. Barometer falling, with high wind at Chicago and Milwaukee to-day. Barometer rising and thermometer rising at Chicago, Detroit, Toledo, Cleveland, Buffalo, and Rochester. High winds probable along the lakes.

This was abundantly justified. It was prepared mainly by Prof. I. A. Lapham, who was then in the employ of the Signal Service.

WEATHER PREDICTIONS.

With the multiplication of the weather maps, there is an increased desire for information as to rules for predicting the weather. It is not an easy matter to give definite rules, for the reason that the conditions are so diverse. The occurrence of rain is dependent upon the direction of the wind in winter, a lake wind carrying relatively warm and moist air to the cooler land has its moisture condensed. On the other hand, if the wind is seen to be likely to shift to the lake in the warm months it is rather a sign of clearing weather.

In winter the path of a storm to the southward of the city tends to cause north winds and much lower temperature. A storm to the north will give higher temperature in its front, but if rapidly moving, the northwest wind will be very cold, especially if a high area follows the storm.

In summer a very high temperature with a low pressure area to the west or southwest is likely to give thunderstorms and squalls.

We have no well marked types of weather such as are so prominent in Europe, where often the same kind of weather will be experienced for a week or ten days. There are, however, oftentimes persistent conditions of pressure in the atmosphere which may tend to repeat abnormal cold or warm spells for a month or more. The best way to show this will be to give charts of isobars for the coldest and warmest months since the work of the Weather Service began.

Fig. 24 is a chart of the weather conditions for the month of January, 1888, which recorded the lowest temperature of the 22 Januarys, and Fig. 25, in like manner, exhibits the opposite conditions during the warmest February (1882) of the series. The latter is a remarkable culmination of a series of high monthly temperatures beginning with the previous August. The amount above normal for each month being as follows: August, +5.5°; September, +7.4° (highest on record); October, +5.2°; November, +2.7; December, +9.9°; January, +4.3°; February, +12.0° (highest on record).

In Fig. 24 we have the usual distribution of pressure which occurs with low temperatures in the Northwest. A marked area of high pressure in the Missouri Valley showing that a series of high areas with accompanying cold waves had moved in succession from the north to the south and southeast, causing the abnormal low temperature. Also, we note the absence of the permanent high area in the southeast and the presence of a well marked low pressure area in the extreme northeast, both of these would have a tendency to cause greater velocity in the northwest winds and an increase of cold.

In Fig. 25 we see just the opposite effect. The high pressure is now seemingly kept back by the Rocky Mountain range. An area of relatively low pressure to the north and of marked high pressure in the southeast states also aid in keeping up the temperature. These figures may be regarded typical to these two opposite kinds of weather. When we see a rather persistent high pressure area in the plateau region we may be sure there will not be severe cold experienced in the Lake region. What determines the movement of these high areas has never been determined. Possibly a tendency to the descent of Arctic cold in British America may be a cause, but this is simply removing the difficulty one step back.

RELATIVE STORM FREQUENCY.

In Professional Paper No. XIV are given charts of relative frequency of storms, and from these are taken the following figures showing the

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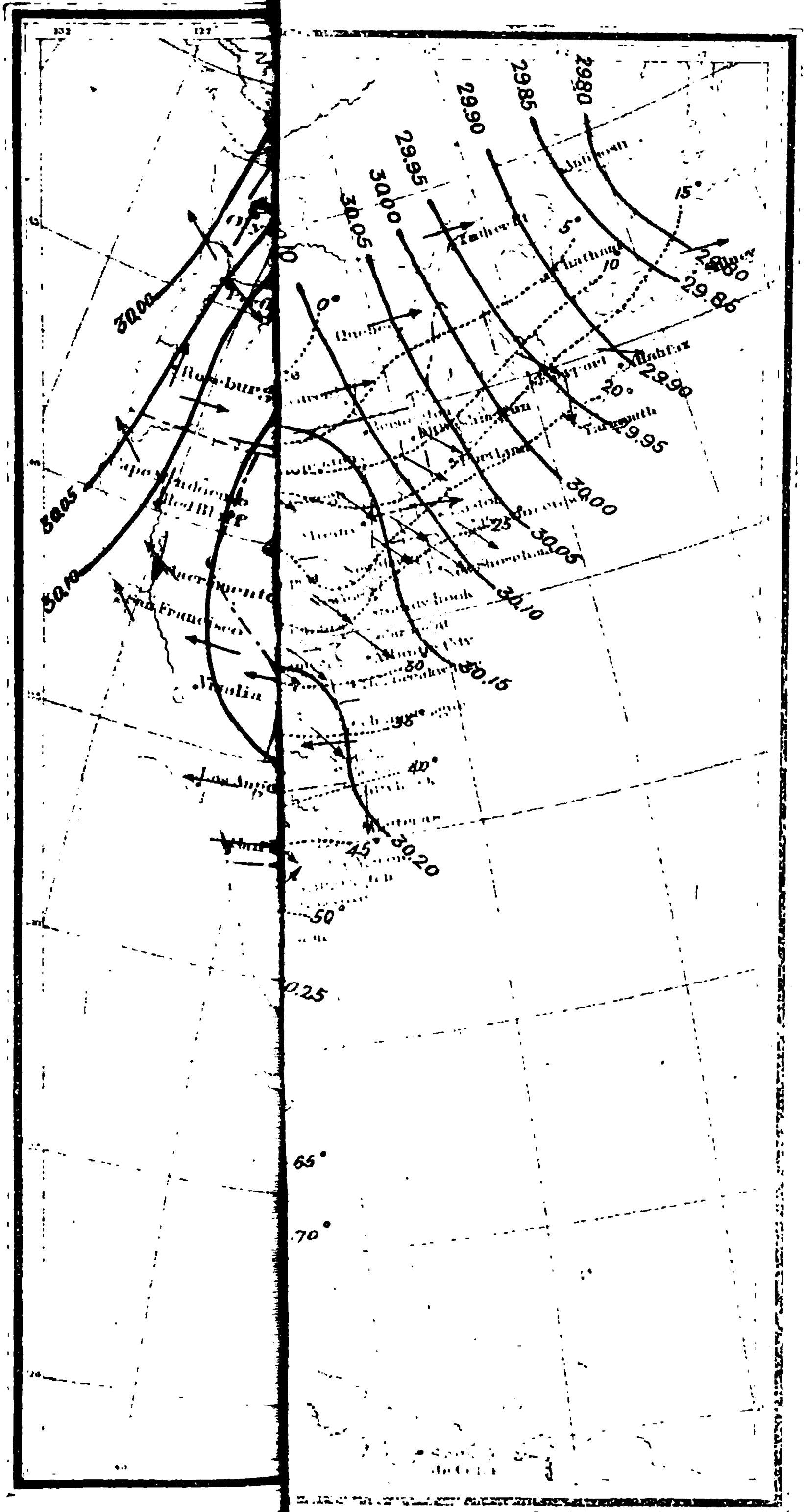

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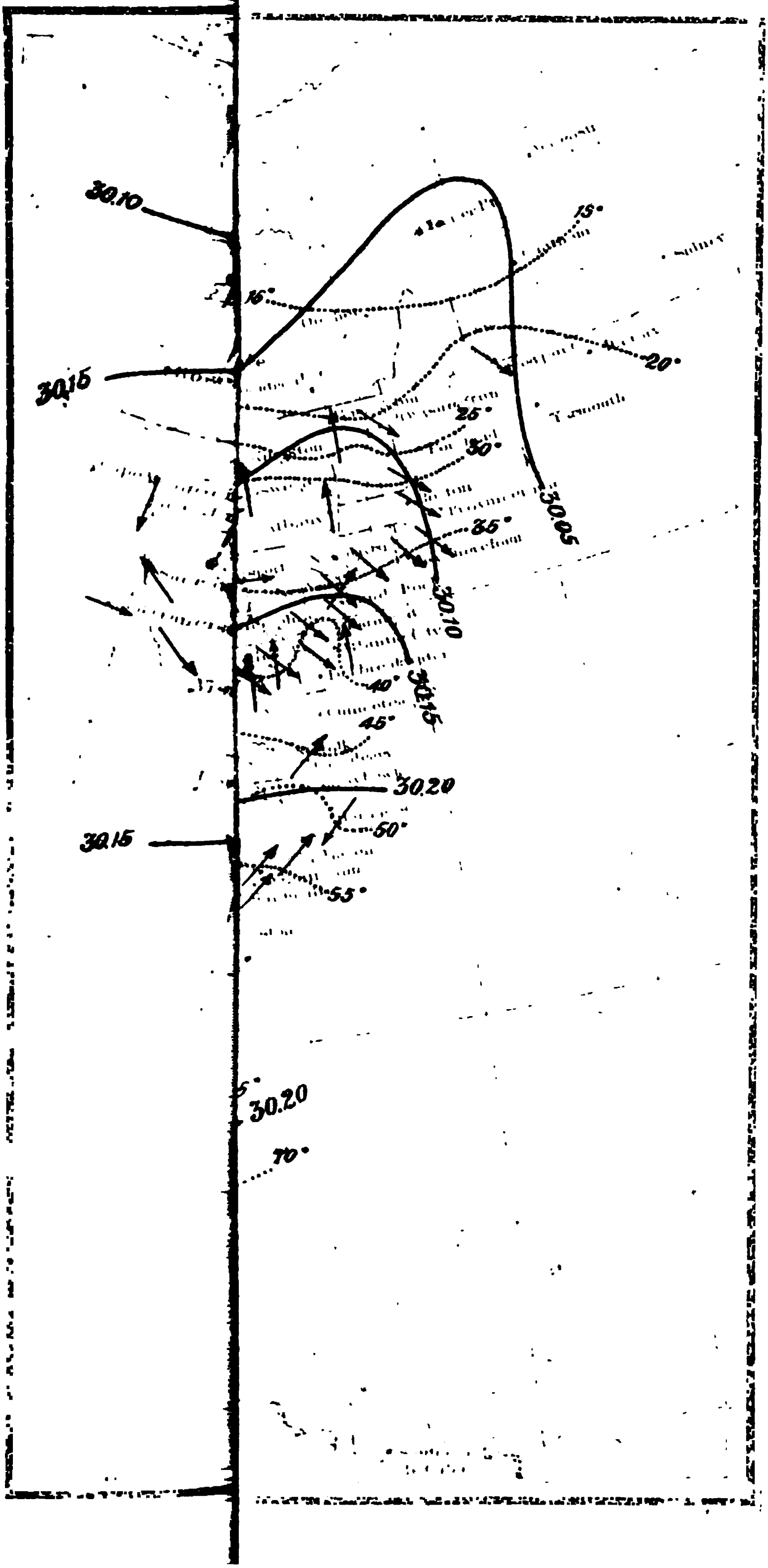
30.10
15°
16°
30.15
20°
25°
30°
30.05
35°
30.10
40°
30.15
45°
30.20
30.15
50°
55°
30.20
70°

number of storms passing over each 5° square near Chicago, or within about 170 miles of the city.

This takes no account of the large number of storms passing more than 170 miles away from which precipitation would occur at the city.

TABLE LV.—*Number of storms near Chicago.*

Month.	Number of storms.	Month.	Number of storms.
January	6 to 8	August	2 to 4
February	4 to 6	September	2 to 4
March	4 to 6	October	4 to 6
April	2 to 4	November	6 to 8
May	4 to 6	December	4 to 6
June	2 to 4		
July	2 to 4	Year	36 to 48

ARE THE SEASONS CHANGING?

This is a very frequent question, and we find frequent allusions to the fact that the temperature is gradually rising, that rains are becoming less abundant, etc. To all this it may be said that the most accurate observations of temperature for more than 100 years at many places in Europe have not shown any such effect.

At Chicago we have just seen that the lowest January temperature, 15.1° (8.9° below normal), occurred in 1888. In examining Table XIX, which gives approximately the mean temperature for 62 years, we see that the mean from 1850–1870 is 1.3° lower than that from 1871–1891; but I have already shown reasons for thinking the former a little too low and the latter too high. The highest annual temperature of the whole series was 53° in 1846. We are entirely safe in assuming that the temperature shows no change in the seasons as a whole. Whether spring is a little earlier now than formerly is a slightly different question, and there are some indications of this.

It was hoped that the indigenous forest growth along the lake would give some idea as to the cumulative effect through hundreds of years of the increased temperature and moisture due to the lake, but diligent inquiry failed to demonstrate any marked effect of this kind. It is quite well known that in the spring of the year the blossoming of flowers on the lake shore is somewhat retarded, oftentimes the season is ten days or a fortnight later than 12 or 15 miles in the interior.

FREEZING OF THE LAKE.

The lake keeps open in the center all the cold season. In the winter of 1874–1875 ice was cut 16 inches thick two or three miles out on the lake, but this is a rare occurrence.

IS THE WATER LEVEL OF LAKE MICHIGAN GRADUALLY LOWERING?

The level of Lake Michigan has reached a stage a little (.16 foot) below the lowest average stage known, that of 1847, and, under the influence of a southerly wind, it has recently gone two feet below the 1847 stage. This remarkable diminution has been commonly ascribed to the great scarcity of rainfall during the past few months. Its serious aspect is shown in the great difficulty, at times, in keeping up the water supply for the city of Chicago, and if there is to be a steady diminution in the level it will necessitate, not many years hence, a radical change in the methods of obtaining this supply. It becomes then of the extremest importance to determine, if possible, whether there has been such a diminution in the lake level through some means other than the scarcity of rainfall, and whether this diminution is likely to continue in years to come.

It is commonly accepted among meteorologists that the rainfall of the earth has remained practically constant for more than 100 years, that is, while there may be a scarcity in some years this will be entirely made up in succeeding years, or, in other words, there is no permanent change in the total rainfall reaching the earth. It is interesting to test this question in respect to the watershed of Lakes Michigan and Huron. The condition of rainfall about Lake Superior, or its water level, does not enter the problem directly, since its height is 602 feet, while that of Huron and Michigan is 582 feet.

An examination of the precipitation records reveals many serious errors, especially in the measurement of snow previous to 1885. The records of voluntary observers, on whom alone we can rely previous to 1871, are also far from satisfactory. However, there is a fair probability that while the absolute amount of precipitation cannot be determined, the relative amount from year to year may be regarded as approximately correct. There is also a slight difficulty in that very few of the records were begun in 1852. Five stations were selected as giving the longest records and fairly well distributed over the watershed. These are Chicago, Milwaukee, Detroit, Marengo, and Peoria, which is near the watershed. The rainfall records from these stations have been combined and then smoothed out by taking the consecutive 5-year means. Table LVI gives the total smoothed rainfall from 1853 to 1891.

TABLE LVI.—*Rainfall at Chicago, Milwaukee, Detroit, Marengo, and Peoria by years.*

Year.	Amount.	Year.	Amount.	Year.	Amount.
	Inches.		*Inches.*		*Inches.*
1853	33.4	1865	30.7	1878	37.7
1854	33.2	1866	31.7	1879	37.9
1855	33.1	1867	33.9	1880	37.1
1856	37.2	1868	32.7	1881	36.8
1857	36.6	1869	32.1	1882	37.2
1858	34.0	1870	33.4	1883	36.6
1859	35.0	1871	33.1	1884	33.8
1860	36.0	1872	30.8	1885	32.7
1861	33.1	1873	32.7	1886	31.4
1862	32.7	1874	34.6	1887	30.5
1863	33.3	1875	36.0	1888	31.2
1864	33.4	1876	36.5	1889	30.4
		1877	37.5		
Mean	34.2	Mean	33.5	Mean	34.5

The most serious discrepancy that has been found has been in the records at Marengo. Mr. Schott gives the following precipitation records at Marengo and Riley, which are about 3 miles apart:

TABLE LVII.—*Rainfall at Marengo and Riley.*

Year.	Marengo.	Riley.
	Inches.	*Inches.*
1863	25.57	40.46
1864	23.91	46.90
1865	30.71	49.90

According to these records there is a difference of over 19 inches in the annual precipitation at two stations only 3 miles apart, which is remarkable. There is also a record of 71.0 inches at Detroit during 1855, which seems excessive. However, these irregularities are partially smoothed out by taking the five stations together, and it would seem as though the fluctuation in the annual rainfall is quite closely indicated by these observations. The records have been divided into three groups, from 1853–1864, 1865–1877, and 1878–1889, and the means of the three are 34.2 inches, 33.5 inches, and 34.5 inches, respectively. It will be seen that the average 12 years precipitation is greatest in the last set. I have also computed the smoothed observations of lake level at Chicago and Milwaukee, and the rainfall by months at Chicago in two groups, 1854–1872 and 1873–1891.

On Fig. 26 accompanying, is a graphical representation of these records; *a* shows (in full lines) the lake level at Chicago and (in dotted lines) the level at Milwaukee. There is a most remarkable and satisfactory correspondence between these curves, showing that the effect of the wind, air pressure, and other slight changes in the atmosphere are practically averaged out in yearly records, or are the same at the two stations.

The Chicago lake level up to the end of 1870 was taken in the river, but since 1871 at the "crib," some two miles from shore. There is a very singular effect to be noticed in the lake crib levels at Chicago. Beginning with 1871, the crib curve gradually draws near the Milwaukee curve and crosses it at 1880, and from 1880 to 1891 it gradually draws away from the Milwaukee curve and on the opposite side. This may be due to a gradual rising of the crib through the action of the waves, though we would naturally expect that the crib, if anything, would settle in the lapse of time. Another explanation would be that the bottom of the lake under the crib has very slowly risen. The amount of water pumped from the well has gradually increased from year to year, and this may cause a diminution of the lake level at that point.

The most marked peculiarity in these curves, however, will be found on comparing the broken curve (rainfall over the watershed of the lake) with the lake level curve. It will be seen that there have been two marked rises in the lake, one in 1860 and the other in 1884. The precipitation curve shows a maximum in 1856, but the whole curve is far below the lake level, a second maximum in 1879 is very much longer continued than the first, and is very close to the top of the lake level maximum in 1884. A portion of this difference may be assigned to the rising of the crib zero, but there is still an outstanding difference of several inches in the effect upon the lake of corresponding amounts of precipitation and evaporation, that is, a given amount of rain and snow, considering the evaporation constant, in 1856, seems to have had a much greater effect in raising the level of the lake than in 1879. A part of this difference may have been due to the rather low-water stand in 1879, or at the time the water level began to rise, but it would appear, on the whole, that the only way of accounting for some of the difference is on the hypothesis that there has been a permanent diminution of the lake level of some 6 inches in 24 years, or ¼ inch per year.

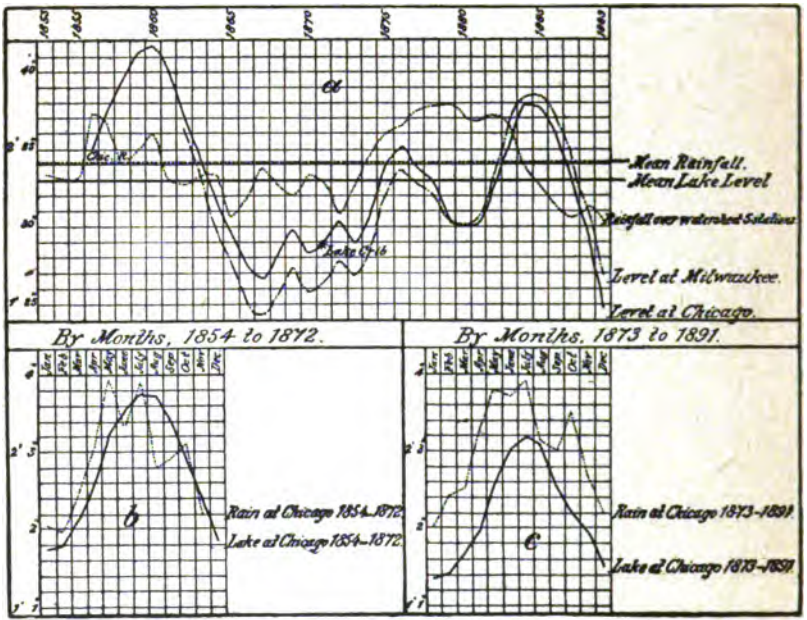

FIG 26.—*Precipitation and lake level.*

The total area of Lakes Michigan and Huron is 44,800 square miles, so that, considering the inflow from Lake Superior as averaging a constant quantity in a long period of years, and the outflow from Lake Huron, due to the precipitation which flows from the watershed, as also averaging a constant quantity, we have between one-fifth and one-sixth of a cubic mile of water per year that is gradually wasting away.

We may attack the problem from still another standpoint. It is known that centuries ago the level of the lakes was far above their present stand. A high level indicates a greater outflow, and this increased outflow would continue until an exact balance was established between the total precipitation on the lakes and that finding its way to them from the watershed, and the outflow. It is impossible to determine whether such a balance had been reached at the beginning of our records, but we may assume that it had.

There seems to be a gradual diminution of the water level of from ¼ to ⅛ inch per year. This may seem an exceedingly small quantity, but it is large enough to show the necessity of conserving with some care the waters of the lakes. It is proposed to increase the depth of the waterway in the Saint Clair River to 21 feet, and also to cut an enormous waterway from Chicago to the Mississippi. These drains upon the lakes would be a serious factor. When we add to this that the water supply of Chicago draws out nearly one-fifteenth cubic mile per year, we see forcibly the necessity of exercising great care in preserving the natural level of Lake Michigan.

METEOROLOGIC SUMMARY.

There is added a monthly and annual summary of all the official weather observations at this station, Table LVIII. The mean dew-point is given in Table LIX. Table LX shows grains per cubic foot of moisture from 1882 to 1891. Table LXI gives the dates of first and last killing frosts.

ABSTRACT OF JOURNAL.

The daily journal contains a description of all auroral phenomena, violent storms, and other facts of interest transpiring since the occupation of this station by the Weather Service. This has been quoted from quite freely. It has also been deemed advisable to quote the observers' experiences during the great fire of October 8–9, 1871.

H. A. HAZEN.

WASHINGTON, D. C., *June* 27, 1892.

TABLE LVIII.—*Meteorological summary, Chicago*, 1871.

Pressure, 29.″+ Latitude 41° 53′ N., longitude 87° 37′ W. Height of barometer, 824′. * 28.″

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
	″	″	″	″	″		″		″	°	°	°	°	°	°	°	°	°		°		°			
Jan	.22	.23	.23	.23	.65	18	8.65	31	1.00	29.1	32.8	30.9	30.9	...	...	...	...	...	...	...	...	...	...	...	...
Feb	.10	.10	.10	.10	.61	10	8.49	17	1.12	29.7	35.6	33.4	32.9	...	...	...	...	...	...	...	...	...	...	...	...
Mar	.05	.02	.04	.04	.42	24	8.41	8	1.01	39.5	45.3	41.2	42.0	...	...	...	...	...	...	...	...	...	...	...	...
Apr	.95*	.89*	.93*	.92*	.48	2	8.41	19	1.07	46.8	56.7	50.8	51.4	...	...	...	...	...	...	...	...	...	...	...	...
May	.15	.10	.13	.13	.56	10	8.86	16	.70	56.2	62.4	56.9	58.5	...	...	...	...	...	...	...	...	...	...	...	...
June	.11	.09	.06	.09	.38	21	8.79	12	.59	...	...	...	66.8	...	...	...	...	...	...	...	...	...	...	...	...
July	.14	.09	.11	.11	.39	23	8.84	6	.55	69.4	76.3	71.0	72.2	...	...	...	...	...	...	...	...	...	...	...	...
Aug	.11	.04	.10	.08	.36	17	8.65	29	.71	69.2	75.9	71.0	72.0	...	...	...	...	...	...	...	...	...	...	...	...
Sept	.32	.26	.29	.29	.62	30	8.98	22	.64	56.0	65.8	59.9	60.6	...	...	...	...	...	...	...	...	...	...	...	...
Oct	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Nov	.19	.17	.18	.18	.58	12	8.68	9	.90	31.9	38.0	34.8	34.9	...	...	...	...	...	...	...	...	...	...	...	...
Dec	.18	.14	.18	.17	.66	27	8.36	23	1.30	18.0	25.0	20.6	21.2	...	...	...	...	...	...	...	...	...	...	...	...
Year	...	...	...	...	.66	...	8.36	...	1.30	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
	″	″		%	%	%	%					*Miles.*	*Miles.*															
Jan	4.12	1.20	14	76	71	74	74	7.2	6.0	6.2	6.5	...	...	...	...	5	7	8	2	24	16	15	15	1	7	7	17	12
Feb	1.46	.78	18	68	67	70	68	5.0	4.8	4.5	4.8	...	...	...	...	5	13	9	5	12	17	15	8	0	15	4	9	6
Mar	2.66	.71	3	75	69	74	73	6.2	6.5	3.0	5.2	...	...	...	...	11	14	15	8	10	13	12	10	0	11	13	7	11
Apr	5.70	1.95	11	68	62	68	66	5.8	7.0	4.5	5.8	...	...	...	...	8	13	7	9	10	21	17	5	0	5	15	10	12
May	3.90	1.03	26	74	63	73	70	5.2	5.2	4.5	5.0	6,545	...	...	...	10	28	16	8	9	10	6	6	0	16	3	12	11
June	5.56	2.13	24	...	...	...	...	4.5	5.2	4.5	4.7	6,090	...	...	...	8	19	9	13	9	8	10	11	3	15	9	6	14
July	2.52	1.57	4	73	60	73	...	3.8	4.0	3.6	3.8	6,205	...	...	...	5	17	12	7	13	22	7	6	4	14	10	7	8
Aug	2.01	.73	5	76	66	76	...	4.0	3.2	2.3	3.2	6,025	...	...	...	9	14	16	10	14	12	10	7	1	16	10	5	8
Sept	.74	.50	15	69	55	66	...	3.2	3.7	3.7	3.5	6,540	...	...	...	7	21	11	2	14	18	5	11	1	16	9	5	4
Oct	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Nov	3.62	1.24	10	78	71	77	...	6.2	6.2	7.0	6.5	...	...	...	...	3	7	13	11	10	14	8	23	1	8	7	15	12
Dec	3.44	2.50	23	84	72	80	...	4.5	5.2	5.2	5.0	8,334	...	...	...	3	2	0	8	17	18	30	15	0	14	7	10	10
Year	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Meteorological summary, 1872.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.19	.20	.20	.20	.61	1	8.72	19	.89	19.8	26.8	22.4	23.0	......	......	......	......	....	....	......	....	.....	......	......	......
Feb	.13	.11	.13	.12	.66	7	8.47	24	1.19	22.0	29.1	25.3	25.5	......	......	......	......	....	....	......	....	.....	......	......	......
Mar	.19	.16	.17	.17	.65	20	8.50	30	1.15	25.2	31.2	28.0	28.1	......	......	......	......	....	....	......	....	.....	......	......	......
Apr	.10	.07	.09	.09	.56	4	8.45	8	1.11	43.3	52.6	45.8	47.2	......	......	......	......	....	....	......	....	.....	......	......	......
May	.11	.06	.11	.09	.47	31	8.60	18	.87	53.4	60.9	53.9	56.1	......	......	......	......	....	....	......	....	.....	......	......	......
June ...	.10	.06	.07	.08	.41	21	8.65	7	.76	65.6	75.9	66.1	69.2	......	......	......	......	98	19	51	16	47	0	4	0
July ...	.13	.09	.11	.11	.28	19	8.74	15	.54	70.5	76.5	69.5	72.2	......	63.6	......	......	97	2	52	5	45	0	4	0
Aug	.19	.16	.18	.18	.29	31	8.89	24	.40	68.6	77.1	69.8	71.8	......	63.4	......	......	93	21	56	2	37	0	4	0
Sept ...	.07	.03	.04	.05	.34	1	8.43	28	.91	59.0	70.3	62.4	63.9	......	54.9	......	......	93	6	37	27	56	0	2	0
Oct.....	.23	.17	.21	.20	.57	24	8.60	15	.97	44.8	56.2	49.3	50.1	......	41.8	......	......	81	4	28	11	53	0	0	3
Nov	.17	.14	.16	.16	.50	17	8.76	7	.74	27.8	35.6	31.2	31.5	......	24.2	......	......	59	10	—2	29	61	9	0	17
Dec	.31	.28	.29	.29	.68	24	8.57	1	1.11	14.4	22.6	19.9	19.0	......	9.4	......	......	46	23	—23	24	69	18	0	31
Year ...	.16	.14	.14	.15	.68	....	8.43	....	1.25	42.9	51.2	45.3	46.5	......	......	......	......	98	....	—23	....	121	......	......	......

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	.01 rain-fall.
Jan	.68	.29	19	86	76	84	82	5.5	6.0	6.2	5.9	8,123	27	nw.	13	6	4	1	3	11	33	25	10	0	4	17	10	7
Feb	.84	.42	5	81	72	78	77	5.8	4.5	4.5	4.9	6,410	37	w.	13	10	21	4	8	17	10	12	4	1	9	10	10	6
Mar	3.79	1.88	30	80	72	78	77	6.2	5.5	3.8	5.2	7,616	34	sw.	18	8	14	3	5	9	16	14	24	0	8	13	10	9
Apr	3.03	.63	21	72	56	71	66	5.0	5.0	4.0	4.7	8,466	46	ne.	15	11	13	11	8	11	24	9	2	1	7	11	5	11
May	3.24	.96	29	74	59	74	69	5.5	4.8	4.2	4.8	6,926	25	sw.	26	13	12	9	13	13	10	18	5	0	9	14	8	9
June	3.45	1.21	6	72	53	76	67	5.5	4.5	3.5	4.5	6,266	......	......	......	6	8	13	6	19	19	9	6	4	9	16	5	9
July	3.09	.53	16	77	65	80	74	3.2	5.0	3.1	3.8	6,223	......	......	......	9	20	6	9	7	23	6	10	3	17	10	4	7
Aug	2.59	.89	28	79	62	81	74	4.5	4.2	3.0	3.9	6,776	......	......	......	11	20	4	4	13	26	4	10	1	13	10	8	11
Sept	6.43	2.70	28	75	56	75	69	4.2	4.5	3.2	4.0	8,832	50	......	24	7	9	6	11	18	21	12	4	2	10	17	3	12
Oct	.65	.38	6	72	53	68	64	3.2	3.0	2.5	2.9	7,439	31	......	30	13	10	8	5	16	13	15	10	3	18	10	3	3
Nov	1.06	.77	4	75	63	71	70	4.8	6.0	5.5	5.4	9,057	31	......	13	0	0	2	15	16	28	27	2	0	8	10	12	11
Dec	.22	.07	1	73	66	68	69	5.8	6.0	5.5	5.8	8,325	32	......	14	3	3	3	4	15	23	21	15	6	5	14	12	9
Year..........	29.07	2.70	....	76	63	75	71	4.9	4.9	4.1	4.6	....	50	......	......	97	134	70	91	165	246	172	102	21	117	152	90	104

Meteorological summary, 1878.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 32°.	Min. below 32°.
Jan....	.110	.083	.107	.100	.60	28	8.41	2	1.19	17.2	23.3	20.8	20.4	29.1	10.1	19.0	19.6	51	15	—16	26	67	18	0	30
Feb....	.110	.131	.154	.132	.62	1	8.58	26	1.04	20.2	27.1	25.0	24.1	36.2	11.1	25.1	23.6	53	19	—18	23	76	7	0	28
Mar....	.130	.128	.137	.132	.77	3	8.61	28	1.16	30.6	38.0	34.3	34.3	42.3	22.5	19.8	32.4	60	14	—12	4	72	5	0	24
Apr....	.045	*.985	.032	.021	.35	30	8.69	8	.66	40.3	45.3	43.3	43.0	51.5	33.9	17.6	42.7	83	5	25	23	58	0	0	11
May....	.080	.072	.064	.072	.53	31	8.65	2	.88	51.9	57.2	52.3	53.8	61.9	42.3	19.6	52.1	87	26	35	30	52	0	0	0
June...	.148	.098	.106	.117	.48	1	8.71	30	.77	68.5	73.8	68.7	70.3	79.4	57.2	22.2	68.3	92	23	44	1	48	0	2	0
July...	.162	.144	.160	.155	.34	10	8.93	25	.41	69.1	73.9	69.5	70.8	77.2	60.3	16.9	68.8	93	16	50	19	43	0	1	0
Aug....	.179	.139	.148	.155	.43	5	8.89	31	.54	68.8	75.9	71.5	72.1	78.5	63.5	15.0	71.0	92	24	53	3	39	0	2	0
Sept....	.140	.084	.122	.115	.50	8	8.77	28	.73	57.2	68.2	60.9	62.1	70.8	54.3	16.5	62.6	88	11	41	19	47	0	0	0
Oct.....	.143	.101	.118	.121	.52	25	8.64	21	.88	44.7	54.5	47.5	48.9	57.5	41.7	15.8	49.6	75	9	23	31	52	1	0	5
Nov....	.084	.052	.045	.060	.66	29	8.41	17	1.25	30.7	37.9	34.4	34.3	40.3	28.2	12.1	34.2	59	4	8	28	51	6	0	18
Dec....	.185	.171	.184	.180	.62	26	8.42	3	1.20	29.8	34.2	31.9	32.0	38.0	26.1	11.9	32.0	60	3	13	5	47	8	0	19
Year...	.126	.099	.115	.113	.77	....	8.41	....	1.36	44.1	50.8	46.7	47.2	55.2	37.6	17.6	46.4	93	....	—18	....	111	45	5	135

Month.	Rainfall			Rel. humidity.				Cloudiness (0-10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	Of rain-fall.
Jan..........	2.56	.81	2	85	77	78	80	6.8	8.5	7.2	7.5	10,529	48	....	......	4	13	4	4	18	24	14	10	2	3	9	19	13
Feb..........	0.47	.25	26	79	72	73	74	4.2	6.2	5.0	5.2	7,980	38	....	......	4	11	4	7	12	20	20	4	2	9	11	8	4
Mar..........	0.89	.26	30	65	58	62	62	5.2	5.5	6.0	5.6	10,938	32	....	......	3	9	4	9	17	9	25	13	4	7	15	9	13
Apr..........	6.22	1.66	5	72	63	74	70	6.5	8.0	7.5	7.3	7,706	32	....	......	20	15	8	2	4	15	6	6	14	5	8	17	17
May..........	7.20	2.82	1	70	58	70	66	6.2	6.5	5.8	6.2	8,555	36	....	......	21	18	9	5	11	15	4	1	9	6	14	11	16
June..........	1.44	.57	26	68	59	70	66	5.2	5.0	3.2	4.5	5,423	30	....	......	14	18	11	7	13	20	4	3	0	6	17	7	6
July..........	4.05	1.65	3	70	63	72	68	5.0	6.0	3.0	4.8	5,908	20	....	......	14	13	9	12	8	26	5	6	0	10	15	6	15
Aug..........	1.58	.58	1	72	60	74	69	4.2	4.8	3.0	4.0	4,455	18	....	......	14	22	5	10	5	20	2	5	10	11	14	6	10
Sept..........	3.53	1.94	28	73	51	66	64	5.2	5.5	4.0	4.9	6,720	35	....	......	11	5	3	10	7	29	8	16	1	9	13	8	8
Oct..........	2.43	1.73	3	73	56	71	67	6.0	6.2	4.5	5.6	6,520	35	....	......	8	6	5	5	13	31	9	15	1	8	13	10	12
Nov..........	1.61	.54	23	78	68	75	74	6.5	6.8	5.8	6.4	5,520	32	....	......	5	9	3	10	8	23	14	18	0	4	9	17	11
Dec..........	4.44	1.24	2	83	79	83	82	6.8	6.2	5.2	6.1	6,799	38	....	......	6	4	3	8	18	25	16	13	0	8	9	14	10
Year..........	36.42	2.82	....	74	64	72	70	5.6	6.3	5.0	5.7	87,053	48	....	... ..	124	143	68	89	134	257	127	110	43	86	147	132	135

Meteorological summary, 1874.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.208	.219	.227	.218	.82	25	8.60	9	1.22	26.6	31.3	28.9	28.9	33.7	22.5	11.2	28.1	60	3	— 6	15	66	8	0	23
Feb	.174	.176	.188	.179	.74	24	8.37	12	1.37	28.0	34.7	31.4	31.4	36.1	24.9	11.2	30.5	56	12	9	24	47	11	0	23
Mar	.157	.127	.140	.141	.66	24	8.32	7	1.34	33.9	39.0	36.5	36.5	43.9	29.0	14.9	36.4	64	17	17	12	47	6	0	18
Apr	.203	.152	.165	.173	.53	20	8.77	14	.76	35.9	41.5	38.5	38.6	45.2	32.3	12.9	38.8	67	13	22	1	45	4	0	10
May....	.124	.096	.102	.107	.30	18	8.69	24	.61	56.0	61.5	57.3	59.3	65.0	51.3	13.7	58.2	89	30	38	1	51	0	0	0
June ...	.097	.099	.087	.094	.34	12	8.65	28	.69	68.6	74.3	68.6	70.5	78.0	62.8	15.2	70.4	95	27	46	1	49	0	3	0
July ...	.153	.105	.080	.113	.29	19	8.75	24	.54	72.1	79.0	73.3	74.8	82.7	66.9	15.8	74.8	99	6	60	29	39	0	7	0
Aug....	.146	.118	.123	.129	.34	4	8.86	10	.48	69.3	75.0	71.1	71.8	78.0	67.1	10.9	72.6	98	11	58	24	40	0	5	0
Sept....	.176	.132	.136	.148	.33	1	8.78	19	.55	62.0	71.0	66.1	66.4	73.6	60.6	13.0	67.1	89	7	44	30	45	0	0	0
Oct.....	.223	.178	.221	.207	.60	13	8.63	28	.97	48.9	57.7	52.4	53.0	59.9	47.5	12.4	53.7	78	1	30	31	48	0	0	1
Nov	.198	.158	.159	.172	.63	18	8.32	23	1.31	36.4	44.2	40.3	40.3	48.9	31.2	17.7	40.0	72	7	0	30	72	3	0	14
Dec	.199	.169	.206	.191	.82	31	8.63	16	1.19	29.9	37.6	32.9	33.5	41.0	24.7	16.3	32.8	52	2	1	29	51	22	0	25
Year ...	.172	.144	.153	.169	.82	....	8.32	....	1.50	47.3	53.9	49.8	50.4	57.2	43.4	13.8	50.3	99	....	— 6	....	105	54	15	114

Month.	Rainfall.			Rel. humidity.				Cloudiness (0-10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	3.47	1.04	21	83	78	76	79	5.8	6.2	5.8	5.9	7,135	30	....	......	11	6	6	5	21	16	13	14	1	7	11	13	14
Feb..........	1.51	.57	12	76	71	74	74	6.0	7.2	5.8	6.3	5,520	36	sw.	23	10	10	8	4	14	17	14	5	2	5	12	11	13
Mar	2.15	1.19	3	77	66	64	69	5.8	5.0	5.0	5.3	7,724	30	sw.	7	10	10	7	4	8	19	14	19	2	9	12	10	9
Apr..........	2.67	1.45	19	67	59	66	64	6.0	5.5	4.0	5.2	7,507	30	n.	8	20	20	13	7	4	15	7	3	1	9	12	9	8
May..........	2.08	.64	15	70	62	70	67	4.2	5.2	4.0	4.5	7,102	25	ne.	3	16	21	8	6	14	19	4	4	1	12	9	10	9
June	3.25	1.45	8	75	60	72	69	4.8	5.2	5.2	5.1	6,187	26	w.	12	7	11	15	9	8	22	10	7	1	9	14	7	10
July..........	.58	.43	7	69	55	48	64	2.5	3.0	3.2	2.9	6,689	30	ne.	24	13	16	13	5	14	22	8	2	0	15	14	2	5
Aug	3.15	2.19	21	73	68	74	72	3.8	4.8	2.5	3.7	6,729	25	....	......	14	27	18	10	10	9	1	4	0	15	12	4	7
Sept	3.76	1.28	5	72	60	67	66	4.2	4.5	3.8	4.2	5,982	30	....	......	4	7	8	15	15	24	7	10	0	14	9	7	9
Oct	2.55	1.53	28	74	64	74	71	5.8	4.8	4.8	5.1	6,246	35	....	......	13	10	9	2	15	18	7	16	3	10	13	8	9
Nov	2.83	.71	19	69	57	64	63	5.5	4.8	4.8	5.1	7,049	35	w.	23	6	1	1	2	24	21	14	20	1	10	10	10	12
Dec..........	.63	.31	16	68	61	73	67	7.0	7.8	4.0	6.2	7,341	40	....	......	9	3	0	4	12	23	20	22	0	7	14	10	7
Year..........	28.63	2.19	....	73	63	70	69	5.1	5.3	4.4	4.9	81,211	40	....	......	133	142	106	73	159	225	119	126	12	122	142	101	112

Meteorological summary, 1875.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan....	.32	.30	.30	.31	.68	17	8.80	29	.88	13.9	22.5	17.4	17.9	26.7	5.5	21.2	16.1	44	23	—20	9	64	20	0	30
Feb....	.21	.18	.19	.16	.73	6	8.61	3	1.12	8.7	20.0	15.5	14.7	24.4	4.9	19.5	14.6	45	3	—13	12	58	20	0	28
Mar....	.10	.09	.12	.10	.54	22	8.33	15	1.21	28.2	35.4	31.8	31.8	37.0	25.0	12.0	31.0	73	30	9	17	64	12	0	21
Apr....	.11	.08	.11	.10	.45	22	8.60	15	.85	39.4	45.3	42.9	42.5	51.6	34.9	16.7	43.2	72	6	17	17	55	2	0	8
May....	.08	.04	.07	.06	.64	16	8.56	7	1.08	53.9	58.2	54.4	55.5	62.2	46.8	15.4	54.5	79	8	27	2	52	0	0	1
June...	.12	.08	.11	.10	.40	13	8.74	1	.66	62.0	65.4	61.9	63.1	70.3	55.6	14.7	62.9	87	11	40	22	47	0	0	0
July...	.13	.11	.11	.12	.51	7	8.83	15	.68	68.0	70.9	67.4	68.8	75.5	62.0	13.5	68.8	88	15	56	6	32	0	0	0
Aug....	.12	.09	.10	.10	.46	22	8.74	10	.70	65.3	72.5	67.3	68.4	75.0	60.8	14.2	67.9	86	31	52	6	34	0	0	0
Sept....	.19	.15	.16	.17	.46	13	8.72	19	.74	57.8	65.4	59.9	61.0	67.9	53.9	14.0	60.9	87	1	40	21	47	0	0	0
Oct.....	.11	.09	.10	.10	.55	12	8.46	29	1.09	43.5	51.8	47.3	47.5	55.4	40.8	14.6	48.1	73	22	30	31	43	0	0	1
Nov....	.19	.16	.17	.17	.68	21	8.67	18	1.01	34.1	39.9	36.9	37.0	43.1	30.0	13.1	36.5	57	11	0	29	57	1	0	13
Dec....	.02	.02	.04	.03	.44	27	8.42	24	1.02	34.8	39.7	35.9	36.8	42.5	29.5	13.0	36.0	68	31	— 1	17	69	3	0	18
Year...	.142	.116	.132	.126	.73		8.33		1.40	42.5	48.9	44.9	45.4	52.6	37.5	15.2	45.0	89		—20		109	58	0	120

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.														Number of days.			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—										Clear.	Fair.	Cloudy.	.01 rain-fall.
													Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.					
Jan..........	.95	.58	18	71	72	70	71	6.2	4.5	3.8	4.8	5,873	25	nw.	8	8	15	29	17	8	9	1	2	4	7	16	8	13
Feb..........	1.99	.85	23	72	72	74	72	5.0	6.0	4.0	5.0	6,590	40	w.	3	6	10	13	35	7	7	4	2	0	9	10	9	9
Mar..........	1.43	.30	1	76	74	72	74	6.2	6.0	5.0	5.8	7,926	38	sw.	15	14	7	8	14	12	9	13	13	3	11	6	14	15
Apr..........	2.32	1.02	12	69	61	66	66	5.8	6.0	3.0	5.0	7,042	30	n.	29	22	8	6	20	6	4	10	13	1	8	13	9	11
May..........	3.64	1.10	28	66	64	70	67	3.8	5.2	1.5	3.5	6,310	30	sw.	8	17	7	4	19	9	18	13	3	3	14	10	7	14
June..........	5.17	1.70	21	73	67	78	73	6.8	5.8	5.0	5.8	6,034	25	nw.	23	22	5	3	14	9	9	11	16	1	6	13	11	15
July..........	7.18	2.29	27	79	73	81	78	4.8	5.2	4.0	4.8	5,072	30	ne.	15	19	2	6	11	7	9	15	21	3	10	13	8	15
Aug..........	3.29	1.22	15	75	62	76	71	4.0	4.5	2.5	3.8	6,234	45	s.	5	9	5	11	19	21	8	9	11	0	12	16	3	10
Sept..........	4.39	3.52	9	77	62	76	72	6.0	5.0	3.5	4.8	5,739	35	n.	9	18	8	2	28	14	6	7	3	4	8	13	9	8
Oct..........	4.36	1.49	6	70	62	70	67	6.2	6.8	5.2	6.0	7,669	32	sw.	25	11	19	9	25	16	5	3	4	1	8	9	14	13
Nov..........	.74	.35	26	71	63	69	67	6.5	6.5	6.0	6.2	6,585	25	ne.	13	8	13	10	13	13	16	6	11	0	5	13	12	10
Dec..........	2.62	.66	24	76	72	78	75	6.5	5.8	5.8	6.0	7,014	26	w.	12	9	13	16	17	13	17	3	4	1	5	11	15	13
Year..........	38.08	3.52		73	67	73	71	5.6	5.6	4.1	5.1	78,088	45	s.	......	163	112	117	232	135	117	95	103	21	103	143	119	146

Meteorological summary, 1876.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A. M.	After-noon.	Night.	Morthly.						A. M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.19	.13	.15	.16	.67	29	8.50	18	1.17	29.5	37.4	32.2	33.0	41.8	23.8	18.0	32.8	65	1	4	10	61	6	0	23
Feb	.16	.13	.16	.15	.78	1	8.59	27	1.19	28.6	35.7	31.1	31.8	39.8	24.0	15.8	31.9	63	10	— 3	2	66	7	0	17
Mar	.11	.09	.11	.10	.63	26	8.27	16	1.36	31.2	36.3	34.3	33.9	39.8	28.2	11.6	34.0	69	10	10	18	59	8	0	20
Apr	.11	.08	.09	.09	.47	1	8.53	13	.94	43.3	49.7	46.5	46.5	54.0	40.9	13.1	47.4	70	27	32	2	38	0	0	0
May	.13	.09	.09	.10	.47	23	8.76	9	.71	56.6	62.8	57.6	59.0	68.0	50.7	17.3	59.4	87	29	35	1	52	0	0	0
June ...	.02	.01	.02	.02	.21	28	8.58	17	.63	65.8	70.9	65.9	67.5	75.0	61.1	13.9	68.0	88	11	47	18	41	0	0	0
July ...	.13	.11	.12	.12	.31	21	8.74	5	.57	71.3	77.1	72.1	73.5	80.8	67.7	13.1	74.2	93	8	57	24	36	0	4	0
Aug	.18	.14	.15	.16	.34	27	8.86	18	.48	70.6	77.1	72.7	73.5	80.3	67.6	12.7	73.9	92	23	54	27	38	0	1	0
Sept ...	.13	.11	.13	.12	.33	16	8.91	20	.42	58.6	64.4	60.4	61.1	67.0	56.5	10.5	61.7	78	1	37	30	41	0	0	0
Oct.....	.09	.03	.05	.06	.53	15	8.51	20	1.02	44.4	53.7	48.7	48.8	57.1	41.6	15.5	49.4	73	30	28	15	45	0	0	0
Nov	.10	.08	.11	.10	.35	30	8.56	2	.79	37.6	41.8	38.5	39.3	45.8	33.2	12.6	39.5	66	12	14	28	52	2	0	11
Dec	.20	.17	.18	.18	.68	16	8.67	12	1.01	17.1	23.0	19.9	20.0	26.9	11.9	15.0	19.4	45	13	—14	9	59	22	0	30
Year ...	.129	.098	.113	.113	.78	....	8.27	....	1.51	46.2	52.5	48.3	49.0	56.4	42.3	14.1	49.4	93	....	—14	....	107	45	5	101

Month.	Rainfall.			Rel. humidity.				Cloudiness (0-10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan	3.22	1.53	18	77	68	74	73	6.0	5.8	5.5	5.8	6,732	40	n.	1	3	3	2	6	20	29	15	13	2	10	7	14	11
Feb	3.90	1.94	9	70	62	71	68	4.8	4.8	4.2	4.5	5,860	22	s.	5	2	7	4	9	21	13	21	10	0	13	9	7	9
Mar	4.04	1.67	16	76	70	78	74	6.2	7.5	6.0	6.5	6,736	35	ne.	28	15	7	14	6	12	11	15	13	0	5	9	17	16
Apr..........	2.07	1.51	13	64	54	67	62	4.5	5.8	3.8	4.8	6,389	30	w.	5	9	13	10	12	11	19	7	9	0	11	10	9	8
May..........	1.85	.79	6	66	57	80	67	3.5	5.2	4.0	4.2	6,297	45	sw.	6	15	11	8	13	12	21	8	3	2	10	15	6	14
June	5.96	1.87	16	73	66	74	71	6.2	6.0	6.2	6.2	5,494	36	ne.	23	9	7	2	10	17	29	10	4	2	4	11	15	17
July	3.11	1.91	10	75	64	78	72	4.8	4.0	2.2	3.8	5,023	24	nw.	5	19	17	6	8	9	20	4	6	4	12	15	4	10
Aug	3.66	1.82	30	75	64	82	73	3.8	4.0	2.0	3.2	4,154	20	....	......	11	13	11	14	20	9	5	4	6	14	14	3	7
Sept..........	3.74	1.72	13	79	69	80	76	6.2	5.5	4.0	5.2	4,885	20	w.	28	20	12	10	5	9	7	5	16	6	9	8	13	11
Oct	1.20	.44	13	67	54	66	63	4.5	5.0	5.0	4.8	6,272	28	sw.	10	6	3	4	8	22	25	13	11	1	13	9	9	9
Nov	3.25	.93	2	75	67	72	72	8.0	8.5	7.5	8.0	5,340	25	sw.	6	8	3	3	6	22	18	10	18	2	2	6	22	12
Dec..........	.48	.13	17	71	65	75	70	6.0	5.0	5.8	5.5	5,903	34	w.	16	3	3	2	6	15	24	14	20	6	5	13	13	13
Year..........	36.48	1.94	....	72	63	75	70	5.4	5.6	4.7	5.2	69,065	45	sw.	......	120	99	76	103	190	225	127	127	31	108	126	132	137

Meteorological summary, 1877.

Month.	Barometer reading (corrected for temp. and inst. error.)									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan....	.24	.20	.23	.22	.57	22	8.64	15	.93	17.6	25.9	22.3	21.9	30.6	14.1	16.5	22.3	56	31	— 4	23	60	15	0	28
Feb....	.28	.25	.27	.27	.77	13	8.73	22	1.04	32.5	40.6	36.1	36.4	43.5	31.1	12.4	37.3	58	18	21	17	37	0	0	12
Mar....	.15	.13	.14	.14	.45	29	8.33	2	1.12	25.7	32.9	29.5	29.4	35.7	22.1	13.6	28.9	65	31	5	4	60	13	0	28
Apr....	.08	.06	.07	.07	.51	2	8.52	19	.99	43.6	48.3	44.2	45.4	53.0	40.2	12.8	46.6	78	23	27	2	51	0	0	2
May....	.17	.13	.14	.15	.39	12	8.73	21	.66	54.2	60.5	55.9	56.9	63.9	50.4	13.5	57.1	86	19	33	2	53	0	0	0
June...	.06	.02	.04	.04	.25	22	8.77	8	.48	64.5	69.3	64.6	66.1	75.2	58.6	16.6	66.9	87	30	45	10	42	0	0	0
July...	.11	.08	.09	.09	.46	24	8.77	18	.69	70.7	76.7	71.8	73.1	81.5	65.8	15.7	73.6	91	8	57	20	34	0	1	0
Aug....	.11	.08	.09	.09	.32	28	8.88	8	.44	67.6	75.6	70.0	71.1	79.9	63.6	16.3	71.8	89	27	55	24	34	0	0	0
Sept....	.17	.12	.14	.14	.36	7	8.88	15	.48	61.9	71.8	65.9	66.5	74.1	59.4	14.7	66.7	86	16	44	18	42	0	0	0
Oct.....	.13	.09	.10	.11	.44	6	8.71	3	.73	50.9	59.1	54.2	54.7	62.5	48.7	13.8	55.6	80	3	35	30	45	0	0	0
Nov....	.15	.13	.14	.14	.59	6	8.41	26	1.18	37.3	42.4	39.5	39.7	46.2	33.7	12.5	40.0	58	13	14	29	44	2	0	11
Dec....	.20	.19	.19	.19	.55	13	8.69	4	.86	40.5	45.7	42.1	42.8	49.1	37.6	11.5	43.4	67	20	22	2	45	1	0	7
Year...	.154	.123	.137	.138	.77	....	8.33	....	1.44	47.2	54.1	49.7	50.3	57.9	43.8	14.2	50.9	91	....	— 4	....	95	31	1	88

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	.01 rain-fall.
Jan..........	1.91	.81	15	76	76	82	78	5.2	5.0	4.5	5.0	6,668	26	ne.	15	5	4	1	6	17	40	11	5	4	11	10	10	8
Feb..........	.06	.06	22	76	68	77	74	4.0	5.0	3.5	4.2	6,531	28	n.	23	21	8	4	5	11	16	8	8	3	9	16	3	2
Mar..........	5.37	.75	12	79	72	82	78	5.2	6.2	5.5	5.6	7,737	32	n.	8	24	10	7	5	10	21	3	13	0	9	13	9	17
Apr..........	2.42	.65	19	72	67	77	72	4.5	5.8	4.8	5.0	6,820	36	sw.	1	29	21	7	5	6	9	4	4	5	12	8	10	11
May..........	1.81	.73	7	74	57	68	66	3.5	4.5	2.5	3.5	6,201	26	n.	21	4	31	13	9	10	16	5	2	3	17	9	5	5
June..........	6.04	2.65	25	74	67	78	73	4.5	5.0	4.2	4.6	5,832	50	nw.	25	9	15	6	6	12	21	9	8	4	6	19	5	15
July..........	2.98	1.47	2	74	65	74	71	3.0	3.2	2.5	3.0	5,277	25	n.	5	3	19	4	16	4	21	10	11	5	18	11	2	8
Aug..........	3.06	1.14	14	77	65	78	74	4.8	4.8	2.2	4.0	4,855	22	sw.	31	13	9	6	18	12	6	8	12	9	11	13	7	1
Sept..........	2.02	1.19	26	79	58	74	70	4.8	3.2	2.5	3.5	5,600	26	ne.	10	7	3	8	27	7	8	7	17	6	11	13	6	7
Oct..........	6.51	2.19	19	82	67	79	76	8.2	6.2	4.8	6.5	6,845	33	ne.	19	8	16	14	17	8	6	2	21	1	1	17	13	14
Nov..........	6.08	1.66	8	80	70	78	76	7.8	7.8	6.5	7.2	6,747	32	n.	9	8	9	19	24	4	7	10	8	1	3	6	21	14
Dec..........	2.75	1.02	18	79	74	80	78	7.0	6.8	5.2	6.2	6,896	24	sw.	15	10	5	8	24	18	11	6	11	0	6	8	17	14
Year..........	41.01	2.65	....	77	67	77	74	5.2	5.3	4.1	4.9	76,009	50	nw.	......	141	150	97	162	119	182	83	120	41	114	143	108	116

Meteorological summary, 1878.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.15	.13	.15	.15	.64	7	8.79	10	.85	29.0	34.2	30.6	31.2	37.3	26.2	11.1	31.8	49	19	— 1	7	50	4	0	18
Feb	.05	.04	.05	.05	.55	26	8.46	21	1.09	33.1	38.6	35.5	35.7	41.6	31.3	10.3	36.4	55	28	17	4	38	1	0	11
Mar	.06	.02	.03	.04	.39	20	8.44	2	.95	41.3	47.7	44.0	44.3	51.8	38.7	13.1	45.3	68	23	25	25	43	0	0	2
Apr	.92*	.89*	.91*	.91*	.23	17	8.46	9	.77	49.0	56.2	51.5	52.2	59.3	45.6	13.7	52.5	75	30	36	1	39	0	0	0
May	.19	.04	.05	.09	.35	22	8.67	2	.68	53.7	58.4	54.6	55.5	61.6	48.9	12.7	55.2	78	24	38	13	40	0	0	0
June ...	.08	.05	.06	.06	.32	5	8.75	2	.57	63.7	68.9	63.6	65.4	71.5	59.1	12.4	65.3	85	30	50	10	35	0	0	0
July ...	.13	.10	.11	.11	.29	23	8.62	26	.67	72.5	78.1	73.9	74.8	81.6	69.0	12.6	75.3	97	16	59	2	38	0	2	0
Aug	.05	.03	.04	.04	.21	30	8.88	8	.33	70.3	77.8	72.9	73.6	80.4	67.8	12.6	74.1	91	8	57	26	34	0	1	0
Sept....	.20	.15	.18	.18	.60	27	8.73	20	.87	60.8	71.5	65.4	65.9	74.7	57.8	16.9	66.2	87	8	43	21	44	0	0	0
Oct.....	.14	.09	.12	.12	.44	27	8.58	16	.86	48.1	57.1	50.8	52.0	60.1	45.5	14.6	52.8	79	1	27	28	52	0	0	3
Nov	.15	.13	.16	.15	.53	3	8.71	27	.82	39.6	47.0	42.6	43.1	49.9	38.1	11.8	44.0	57	1	31	1	26	0	0	1
Dec	.16	.15	.17	.16	.64	12	8.55	3	1.09	21.3	26.7	23.0	23.7	29.3	18.4	10.9	23.9	46	3	— 9	24	55	15	0	25
Year ...	.182	.143	.161	.163	.64	....	8.44	....	1.20	48.5	55.2	50.7	51.5	58.3	45.5	12.7	51.9	97	....	— 9	....	106	20	3	60

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.														Number of days—			
													Maximum.			Number of times blowing from—													
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	.01 rainfall.
Jan	1.31	.72	31	77	74	80	77	6.0	7.2	5.8	6.2	7,008	23	ne.	31	10	14	4	5	24	11	13	12	0	5	12	14	15
Feb..........	2.12	.74	21	80	71	79	77	6.8	6.2	6.2	6.5	6,202	28	ne.	9	10	27	5	7	14	12	1	6	2	5	10	13	15
Mar	4.39	1.19	28	76	68	76	74	7.2	6.8	4.5	6.2	7,182	35	s.	5	9	16	10	15	12	15	5	11	0	5	16	10	16
Apr..........	5.57	1.53	24	75	61	74	70	6.2	7.2	4.5	6.0	6,414	36	s.	10	12	22	9	7	12	12	13	3	0	7	11	12	13
May	5.22	1.16	29	70	61	75	69	5.0	5.2	4.0	4.8	5,093	25	e.	29	3	13	19	11	10	14	16	6	1	9	12	10	14
June..........	3.02	.87	29	66	62	76	68	5.0	5.8	4.0	5.0	4,607	25	s.	2	6	16	14	16	8	18	9	3	0	8	15	7	12
July..........	6.09	4.14	25	75	63	76	72	5.8	5.0	4.5	5.0	4,541	25	e.	26	0	36	17	17	3	14	2	3	1	7	15	9	10
Aug..........	3.66	1.36	18	76	61	76	71	4.8	3.8	3.0	3.8	4,599	22	sw.	8	4	21	11	13	9	25	5	5	0	12	16	3	15
Sept	1.99	1.15	25	76	58	72	68	5.5	4.5	3.2	4.5	5,220	28	sw.	25	3	9	2	11	11	32	8	14	0	11	13	6	10
Oct	5.17	1.41	16	74	63	75	71	5.8	6.0	4.5	5.5	6,670	27	sw.	16	7	5	2	3	14	38	11	13	0	7	14	10	13
Nov	.83	.21	16	78	69	78	75	5.8	5.5	4.2	5.2	4,847	26	sw.	2	14	7	10	6	6	21	11	13	2	8	15	7	10
Dec..........	2.58	.69	21	77	68	83	76	6.2	6.5	5.2	6.0	5,284	27	w.	3	3	3	4	4	4	30	20	23	2	9	9	13	19
Year..........	41.95	4.14	....	75	65	77	72	5.8	5.8	4.5	5.4	67,667	36	s.	......	81	189	107	115	127	242	114	112	8	93	158	114	162

Meteorological summary, 1879.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.																
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	Afternoon.	Night.	Monthly.						A.M.	Afternoon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan....	.197	.182	.198	.192	.54	25	8.72	25	.82	16.9	26.1	21.3	21.4	28.3	14.2	14.1	21.2	49	27	—18	3	67	17	0	27
Feb....	.182	.160	.168	.170	.60	27	8.64	25	.95	24.7	30.4	27.2	27.4	33.6	20.3	13.3	27.0	51	10	— 6	27	57	11	0	26
Mar....	.187	.145	.163	.165	.68	3	8.78	26	.90	34.9	43.3	39.1	39.1	48.3	32.8	15.5	40.6	71	8	16	15	55	2	0	11
Apr....	.129	.097	.113	.113	.49	22	8.42	10	1.07	44.0	50.2	46.1	46.8	54.4	40.3	14.1	47.4	80	23	17	3	63	1	0	3
May....	.170	.141	.136	.149	.54	8	8.71	4	.83	55.6	60.7	56.5	57.6	66.0	49.7	16.3	57.8	87	12	39	1	48	0	0	0
June...	.138	.113	.110	.120	.48	18	8.58	15	.90	62.2	68.1	63.7	64.7	71.5	57.1	14.4	64.3	87	24	43	1	44	0	0	0
July...	.117	.082	.090	.096	.33	5	8.83	11	.50	73.0	79.7	75.1	75.9	82.9	68.4	14.5	75.6	93	15	60	5	33	0	3	0
Aug....	.127	.091	.100	.106	.30	30	8.86	22	.44	68.6	76.5	72.6	72.6	78.7	65.9	12.8	72.3	91	2	52	17	39	0	1	0
Sept...	.218	.180	.205	.201	.51	20	8.78	16	.73	55.9	66.7	61.1	61.2	68.5	53.6	14.9	61.0	83	30	39	25	44	0	0	0
Oct....	.253	.214	.240	.236	.75	25	8.76	29	.99	56.3	64.8	58.7	59.9	67.6	54.0	13.6	60.8	84	5	28	31	56	0	0	1
Nov....	.175	.141	.173	.163	.60	29	8.67	14	.93	38.0	45.7	42.0	41.9	49.8	35.0	14.8	42.4	69	8	16	20	53	1	0	13
Dec....	.171	.154	.164	.163	.53	18	8.61	6	.92	28.0	32.3	30.6	30.3	39.0	23.2	15.8	31.1	62	5	— 2	26	64	7	0	22
Year...	.172	.142	.155	.156	.75	....	8.42	....	1.32	46.5	53.7	49.5	49.9	57.4	42.9	14.5	50.1	93	....	—18	....	111	39	4	103

Month.	Rainfall.			Rel. humidity.				Cloudiness (0-10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	.54	.41	15	77	67	80	75	4.8	5.0	5.0	5.0	4,999	26	sw.	24	2	4	2	7	1	28	33	15	1	8	14	9	9
Feb..........	1.47	.33	11	82	67	75	74	7.5	5.5	5.0	6.0	5,106	22	nw.	1	5	8	4	3	14	14	21	14	1	4	14	10	15
Mar..........	2.37	.87	5	78	64	77	74	6.8	6.2	4.2	5.7	5,440	25	sw.	24	9	10	10	6	13	17	15	10	3	5	15	11	16
Apr..........	1.93	1.45	9	69	55	67	64	3.5	4.0	2.8	3.5	5,668	26	sw.	10	25	11	10	8	15	7	3	7	4	14	10	6	10
May..........	3.89	2.52	25	71	58	70	66	5.0	5.0	3.2	4.5	5,434	25	n.	31	24	15	11	17	14	6	4	0	2	15	8	8	8
June..........	3.18	1.02	21	72	57	71	67	5.2	4.8	3.2	4.5	5,132	26	n.	21	19	14	9	7	16	15	3	4	3	10	11	9	12
July..........	5.58	3.25	6	70	58	72	66	4.2	3.8	2.2	3.5	4,586	20	nw.	6	4	17	11	9	9	27	8	4	4	15	12	4	7
Aug..........	.45	.16	6	70	54	66	63	5.0	4.5	3.2	4.2	4,762	20	s.	12	8	20	5	8	14	25	4	1	8	10	16	5	7
Sept..........	1.18	.36	14	72	51	67	63	4.5	5.2	3.0	4.2	4,895	28	sw.	16	13	5	6	6	18	19	7	13	3	8	17	5	12
Oct..........	2.72	1.43	17	74	56	69	66	6.0	5.0	3.2	4.8	4,625	20	nw.	2	3	6	2	9	26	18	14	9	6	5	20	6	10
Nov..........	4.93	1.50	28	73	59	72	68	7.5	5.2	4.8	5.8	5,354	26	s.	24	5	3	1	3	15	28	15	12	8	4	12	14	12
Dec..........	2.47	1.10	9	73	64	73	70	7.0	5.8	6.8	6.5	6,154	25	sw.	10	2	10	4	13	13	20	21	9	1	3	14	14	17
Year..........	30.71	3.25	....	73	59	72	68	5.6	5.0	3.9	4.8	62,155	28	sw.	......	119	123	75	96	168	224	148	98	44	101	163	101	135

Meteorological summary, 1880.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan....	.117	.102	.119	.113	.57	....	8.48	....	1.09	38.2	42.8	39.3	40.1	47.5	32.1	15.4	39.8	61	11	19	31	42	0	0	12
Feb....	.142	.110	.146	.123	.83	....	8.59	....	1.24	30.4	38.8	34.6	34.6	42.5	27.1	15.4	34.8	63	26	12	5	51	6	0	17
Mar....	.184	.158	.166	.169	.57	....	8.18	....	1.39	33.3	42.2	38.3	37.9	45.3	31.4	13.9	38.4	60	31	19	15	41	1	0	14
Apr....	.035	.033	.055	.041	.46	....	8.41	....	1.05	44.1	52.8	48.5	48.5	58.0	40.3	17.7	49.2	80	18	27	11	53	0	0	3
May....	.127	.099	.091	.106	.52	....	8.61	....	.91	61.0	68.0	63.7	64.2	72.1	57.9	14.2	65.0	85	7	37	1	48	0	0	0
June...	.104	.080	.082	.089	.41	....	8.41	....	1.00	66.5	74.8	68.4	69.9	77.5	63.8	13.7	70.6	91	11	52	15	39	0	1	0
July...	.122	.109	.110	.114	.30	....	8.89	....	.41	69.0	77.2	70.9	72.4	79.7	66.7	13.0	73.2	95	13	57	20	38	0	4	0
Aug....	.160	.134	.148	.147	.37	....	8.85	....	.52	68.8	77.3	71.2	72.4	80.1	65.3	14.8	72.7	93	18	53	4	40	0	1	0
Sept....	.183	.153	.166	.167	.42	....	8.83	....	.59	57.9	67.6	61.9	62.5	70.0	55.3	14.7	62.6	85	5	40	30	45	0	0	0
Oct.....	.179	.150	.165	.165	.52	....	8.55	....	.97	45.6	56.4	50.5	50.8	59.3	43.5	15.8	51.4	78	10	28	18	50	0	0	2
Nov....	.268	.238	.262	.256	.75	....	8.57	....	1.18	27.3	35.8	31.0	31.4	39.0	24.2	14.8	31.6	65	3	1	21	64	10	0	20
Dec....	.179	.175	.181	.178	.75	....	8.47	....	1.28	20.2	25.5	23.2	23.0	30.7	17.4	13.3	24.0	50	5	—15	29	65	11	0	27
Year...	.150	.128	.141	.140	.83	....	8.18	....	1.65	46.9	54.9	50.1	50.6	58.5	43.8	14.7	51.1	95	....	—15	....	110	28	6	95

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	or rain-fall.
Jan..........	3.53	.95	4	78	70	71	73	6.2	6.8	4.2	5.8	5,232	29	w.	9	9	2	8	3	15	17	19	8	12	6	16	9	14
Feb..........	2.91	.70	11	66	61	62	63	5.5	6.5	4.8	5.5	6,053	32	w.	28	4	5	3	8	11	24	18	13	1	7	12	10	12
Mar..........	2.23	1.08	27	70	54	61	62	6.2	5.8	4.2	5.5	6,823	27	ne.	12	9	8	7	15	12	20	12	10	0	9	15	7	10
Apr..........	5.20	1.65	24	70	53	66	63	5.0	6.0	5.0	5.2	8,214	36	sw.	15	7	10	8	9	14	22	11	8	1	7	14	9	17
May..........	4.97	1.26	8	72	57	71	66	4.5	4.5	3.0	4.0	6,141	28	sw.	9	2	13	7	9	24	22	6	7	3	16	8	7	11
June..........	3.50	1.05	14	76	57	76	69	5.2	5.2	3.5	4.8	5,094	36	sw.	7	7	6	10	6	12	24	11	2	12	8	14	8	13
July..........	3.07	.84	8	78	65	77	73	3.2	6.2	4.2	4.5	5,028	24	sw.	26	10	12	10	9	9	25	8	7	3	12	18	1	9
Aug..........	4.47	1.23	24	76	61	77	72	4.8	3.8	4.2	4.2	5,726	24	ne.	2	2	24	10	15	4	23	6	7	2	13	11	7	14
Sept..........	2.25	.89	18	75	57	72	68	4.8	5.2	3.5	4.5	6,046	23	s.	15	1	15	7	5	17	24	10	9	2	13	9	8	11
Oct..........	3.09	1.79	3	75	55	68	66	5.0	4.8	4.5	4.8	6,902	30	sw.	16	8	5	7	6	22	22	9	14	0	11	11	9	10
Nov..........	.87	.45	10	72	60	67	66	4.8	6.0	6.0	5.5	6,614	28	w.	11	4	1	1	4	18	22	30	10	0	12	7	11	9
Dec..........	1.01	.45	4	73	70	74	72	6.0	7.5	5.8	6.5	6,319	32	w.	5	10	6	4	4	9	14	34	11	1	6	10	15	13
Year..........	37.10	1.65	....	74	60	70	68	5.1	5.7	4.4	5.1	74,192	36	sw.	......	73	107	82	93	167	259	174	106	37	120	145	101	143

Meteorological summary, 1881.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A. M.	After-noon.	Night.	Monthly.						A. M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.213	.185	.213	.204	.70	17	8.57	13	1.13	15.6	23.3	19.5	19.5	27.9	10.8	17.1	19.4	41	29	—13	14	54	21	0	31
Feb	.194	.170	.183	.182	.64	4	8.37	12	1.27	21.5	27.8	24.8	24.7	32.4	17.7	14.7	25.0	51	26	8	16	43	14	0	27
Mar	.975*	.959*	.986*	.973*	.37	14	8.38	19	.99	29.3	34.9	32.4	32.2	37.9	26.9	11.0	32.4	48	16	11	1	37	3	0	28
Apr	.118	.109	.109	.112	.43	30	8.72	15	.71	38.1	45.3	41.0	41.5	48.0	35.5	12.5	41.8	77	25	17	1	60	1	0	8
May....	.162	.132	.134	.143	.49	3	8.84	14	.65	58.6	65.1	59.2	61.0	68.9	53.2	15.7	61.0	87	12	37	2	50	0	0	0
June ...	.057	.058	.047	.054	.28	23	8.74	2	.54	60.4	66.6	62.0	63.0	70.0	56.4	13.6	63.2	89	28	46	4	43	0	0	0
July ...	.162	.145	.130	.146	.39	2	8.79	21	.60	69.4	77.4	72.0	72.9	80.8	66.0	14.8	73.4	93	9	57	1	36	0	5	0
Aug....	.167	.147	.137	.150	.36	25	8.92	12	.44	71.3	79.2	74.5	75.0	81.8	68.9	12.9	75.4	98	4	58	8	39	0	5	0
Sept....	.097	.059	.073	.076	.33	18	8.54	14	.79	64.9	75.2	68.5	69.5	78.0	62.5	15.5	70.2	94	5	49	11	45	0	2	0
Oct.....	.196	.174	.186	.185	.61	5	8.69	29	.92	53.2	59.4	55.2	55.9	62.0	50.2	11.8	56.1	77	12	41	19	36	0	0	0
Nov	.170	.141	.172	.161	.73	10	8.66	12	1.07	37.4	43.3	39.0	39.9	46.8	33.3	13.5	40.0	64	17	14	24	50	1	0	10
Dec	.196	.176	.197	.190	.60	15	8.74	28	.86	34.6	39.9	36.6	37.1	43.0	32.5	10.5	37.8	59	13	13	31	46	2	0	11
Year ...	.142	.121	.131	.131	.73	....	8.37	....	1.36	46.2	53.1	48.7	49.3	56.5	42.8	13.7	49.6	98	....	—13	....	111	42	12	115

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Veloc ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	.87	.24	15	71	68	67	69	4.8	6.8	6.0	5.9	5,358	26	e.	31	16	5	8	5	3	15	25	13	3	7	9	15	10
Feb..........	5.98	1.34	7	73	69	74	72	6.2	7.8	5.0	6.2	5,723	26	n.	27	6	4	7	19	16	8	8	14	2	6	9	13	16
Mar	2.99	1.04	19	78	71	78	76	5.8	7.2	6.5	6.5	5,774	35	ne.	19	15	12	11	3	2	12	18	15	4	5	10	16	12
Apr..........	1.84	.83	11	69	59	70	66	5.8	5.5	4.0	5.1	5,083	21	nw.	1	12	14	7	11	4	15	13	13	1	7	14	9	12
May..........	1.85	.62	9	72	55	70	66	3.0	3.8	2.5	3.0	5,568	24	w.	14	25	14	10	8	10	16	4	5	1	16	11	4	10
June	5.93	1.43	7	78	66	77	74	6.8	5.8	3.8	5.5	5,768	32	sw.	29	31	11	7	7	7	11	11	5	0	7	15	8	14
July	4.31	1.69	21	78	59	75	70	4.3	4.1	2.4	3.6	4,862	20	nw.	24	15	17	9	8	4	15	15	10	0	17	8	6	10
Aug..........	.54	.30	6	69	53	69	64	3.9	3.7	2.5	3.4	5,501	20	sw.	30	14	22	9	15	15	13	3	2	0	15	13	3	4
Sept..........	4.34	1.08	15	76	60	73	70	5.0	5.0	2.9	4.3	5,906	27	sw.	24	12	5	7	6	23	27	6	2	2	8	16	6	13
Oct	6.89	1.15	14	84	71	83	79	5.9	6.1	5.2	5.7	5,768	23	sw.	15	10	14	8	12	17	15	5	8	4	6	12	13	17
Nov.	5.97	3.18	11	81	72	78	77	5.6	5.9	5.6	5.7	7,619	28	se.	11	3	3	2	6	15	24	28	8	1	7	13	10	12
Dec..........	2.67	1.14	21	86	77	82	82	5.1	6.7	4.7	5.5	6,606	26	sw.	16	7	7	3	4	12	26	20	14	0	10	11	10	9
Year..........	44.18	3.18	....	76	65	75	72	5.2	5.7	4.3	5.0	69,536	35	ne.	......	166	128	88	104	128	197	156	110	18	111	141	113	139

Meteorological summary, 1882.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	Afternoon.	Night.	Monthly.						A.M.	Afternoon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.221	.185	.211	.206	.79	23	8.54	26	1.25	25.6	31.3	28.1	28.3	35.8	21.5	14.3	28.6	58	26	1	17	57	9	0	28
Feb	.134	.096	.120	.117	.62	24	8.44	21	1.18	34.0	42.8	37.8	38.2	46.4	31.6	14.8	39.0	62	12	10	22	52	2	0	14
Mar	.153	.117	.138	.136	.68	7	8.52	26	1.16	35.0	41.2	38.7	38.3	46.1	33.2	12.9	39.7	63	29	22	24	41	0	0	13
Apr	.143	.136	.130	.136	.38	17	8.34	19	1.04	43.4	48.4	45.8	45.9	53.7	38.4	15.3	46.0	76	6	25	11	50	0	0	3
May	.109	.091	.094	.098	.50	2	8.63	10	.87	49.5	55.2	50.5	51.7	58.5	44.4	14.1	51.4	76	8	34	2	41	0	0	0
June ...	.023	.013	.010	.015	.28	20	8.56	18	.72	61.2	66.7	62.8	63.6	72.0	56.1	15.9	64.0	88	24	42	1	46	0	0	0
July ...	.153	.142	.144	.146	.42	22	8.92	7	.50	65.6	72.3	67.8	68.6	75.2	62.2	13.0	68.7	90	27	55	5	34	0	0	0
Aug	.124	.105	.120	.116	.38	20	8.87	8	.51	67.9	75.1	70.5	71.2	76.6	66.2	10.4	71.4	87	22	51	10	36	0	0	0
Sept....	.212	.192	.203	.202	.56	25	8.91	18	.65	60.7	69.4	65.0	65.0	70.8	59.0	11.8	64.9	87	18	42	22	45	0	0	0
Oct.....	.149	.117	.127	.131	.45	19	8.67	30	.78	52.5	60.9	56.0	56.5	64.2	51.8	12.4	58.0	77	6	40	29	37	0	0	0
Nov	.239	.216	.237	.231	.71	2	8.81	23	.90	39.3	44.3	41.5	41.7	48.5	36.6	11.9	42.6	72	11	21	24	51	0	0	10
Dec	.172	.153	.181	.169	.73	7	8.57	20	1.16	23.5	28.6	25.8	26.0	32.9	20.3	12.6	26.6	45	1	— 7	8	52	12	0	26
Year ...	.153	.131	.143	.142	.79	....	8.34	....	1.45	46.5	53.0	49.2	49.6	56.7	43.4	13.3	50.1	90	....	— 7	....	97	23	0	94

Month.	Rainfall.			Rel. humidity.				Cloudiness (0-10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	1.55	.49	7	83	84	83	83	4.1	6.7	5.2	5.3	6,926	30	sw.	26	2	1	7	9	10	22	26	16	0	8	17	6	12
Feb..........	2.24	1.35	28	82	71	78	77	5.1	5.7	3.8	4.9	6,625	27	ne.	20	2	5	4	5	13	22	19	14	0	10	8	10	11
Mar	3.43	1.43	9	85	74	81	80	6.6	6.4	5.8	6.3	7,778	32	w.	21	5	12	8	11	14	8	17	18	0	5	13	13	14
Apr..........	6.72	1.58	22	78	65	74	72	6.4	6.7	5.2	6.1	7,275	28	ne.	9	11	24	14	7	6	9	11	8	0	5	15	10	12
May	5.52	1.77	26	76	64	74	71	5.8	6.7	5.7	6.1	7,232	27	ne.	6	21	18	10	11	12	8	8	4	1	6	12	13	14
June	5.71	1.92	2	82	69	81	77	6.4	6.7	4.7	5.9	5,916	24	sw.	18	12	19	10	5	3	21	13	6	1	5	16	9	14
July.........	3.43	1.00	30	74	59	72	68	3.9	4.8	4.1	4.3	5,573	21	sw.	27	8	17	7	11	9	24	12	5	0	13	9	9	13
Aug	4.96	1.69	22	85	66	81	77	5.6	5.4	3.6	4.9	4,997	16	n.	1	9	25	11	6	7	21	7	7	0	9	17	5	16
Sept	.91	.63	1	79	61	74	71	5.0	4.1	2.3	3.8	5,695	21	ne.	11	2	21	11	14	6	17	11	8	0	13	14	3	6
Oct	3.40	1.17	8	81	67	81	76	4.5	5.2	4.0	4.6	5,733	27	sw.	30	2	11	17	10	22	13	10	8	0	11	14	6	12
Nov	1.48	.45	5	80	71	76	76	6.6	7.3	6.0	6.6	6,095	24	ne.	2	5	10	9	12	13	16	18	7	0	3	14	13	14
Dec..........	1.99	.81	20	77	70	76	75	5.7	6.0	5.0	5.6	6,377	28	w.	4	1	0	3	14	10	23	29	13	0	9	10	12	14
Year.........	41.34	1.92	....	80	68	78	75	5.5	6.0	4.6	5.4	76,222	32	w.	......	80	163	111	115	125	204	181	114	2	97	159	109	152

Meteorological summary, 1883.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.														
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan.....	·201	·182	·210	·198	·66	23	8·49	10	1·17	14·6	19·1	15·2	16·3	24·8	8·0	16·8	16·4	40	13	—17	22	57	20	0	31
Feb.....	·343	·310	·316	·323	·78	18	8·67	14	1·11	18·4	27·3	23·2	23·0	30·4	14·7	15·7	22·6	57	16	— 9	1	66	13	0	26
Mar	·138	·120	·135	·131	·62	7	8·57	10	1·05	28·1	34·7	31·5	31·4	39·4	24·8	14·6	32·1	62	14	10	7	52	6	0	26
Apr	·066	·046	·045	·052	·37	2	8·54	10	·83	42·1	48·9	45·9	45·6	54·1	39·5	14·6	46·8	78	14	28	1	50	0	0	2
May	·060	·041	·050	·050	·42	6	8·61	14	·81	50·1	55·3	51·0	52·1	60·5	45·5	15·0	53·0	80	18	36	21	44	0	0	0
June ...	·056	·038	·037	·044	·43	1	8·67	10	·76	61·7	67·6	63·0	64·1	71·2	57·7	13·5	64·4	84	16	48	10	36	0	0	0
July....	·124	·109	·110	·114	·43	18	8·78	12	·65	66·9	76·2	69·9	71·0	78·9	62·4	16·5	70·6	91	3	51	9	40	0	1	0
Aug	·208	·187	·190	·195	·45	6	8·92	19	·53	64·6	72·6	67·6	68·3	74·1	61·7	12·4	67·9	89	19	54	4	35	0	0	0
Sept....	·208	·174	·191	·191	·61	9	8·74	24	·87	56·9	64·7	60·5	60·7	66·7	54·4	12·3	60·6	84	15	42	26	42	0	0	0
Oct......	·218	·200	·219	·212	·70	16	8·56	29	1·14	49·0	54·5	51·8	51·8	57·7	46·7	11·0	52·2	78	8	38	21	40	0	0	0
Nov	·190	·161	·165	·172	·73	16	8·68	9	1·05	37·1	45·7	41·7	41·5	49·9	34·5	15·4	42·2	62	4	10	16	52	2	0	12
Dec.....	·159	·157	·182	·166	·57	22	8·59	17	·98	26·7	33·8	29·9	30·1	38·6	23·4	15·2	31·0	57	7	0	19	57	8	0	22
Year ...	·164	·144	·154	·154	·78	....	8·49	....	1·29	43·0	50·0	45·9	46·3	53·9	39·4	14·4	46·6	91	....	—17	....	108	49	1	119

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	·01 rain-fall.
Jan..........	1·74	·60	16	74	67	74	72	5·9	6·3	4·5	5·6	7,140	27	sw.	13	0	3	6	11	5	30	25	13	0	9	12	10	16
Feb..........	4·74	1·94	16	73	62	70	68	4·1	5·6	5·3	5·0	5,789	24	sw.	16	1	5	9	3	6	26	25	8	1	7	15	6	12
Mar..........	·42	·18	6	66	52	61	60	5·2	5·7	4·1	5·0	6,704	28	ne.	18	15	18	4	4	5	17	16	14	0	11	12	8	8
Apr	3·72	1·32	5	71	58	64	64	6·0	5·2	3·5	4·9	7,328	33	ne.	22	18	15	11	6	13	16	9	0	2	9	15	6	11
May	7·32	2·39	9	75	61	72	69	7·5	7·3	5·4	6·7	6,705	32	s.	18	19	8	12	13	10	13	9	9	0	4	14	13	17
June	5·61	1·20	12	78	67	77	74	5·4	7·2	3·7	5·4	5,972	25	w.	19	23	5	6	9	10	22	9	6	0	7	14	9	13
July	5·53	1·77	4	76	59	74	70	5·2	4·8	3·2	4·4	5,901	21	sw.	16	14	2	5	10	11	32	11	6	2	13	11	7	11
Aug..........	1·21	1·05	27	74	59	71	68	2·9	4·5	3·0	3·5	4,508	20	w.	20	15	17	9	8	4	24	6	6	4	16	10	5	4
Sept..........	1·36	·68	23	76	60	71	69	3·9	4·8	2·9	3·9	4,783	21	n.	16	17	18	10	10	6	15	5	6	3	14	12	4	8
Oct..........	7·36	1·94	25	78	66	72	72	7·0	7·4	6·4	6·9	5,925	21	e.	17	14	17	12	11	6	10	7	8	8	6	8	17	19
Nov	5·26	3·39	5	72	61	66	66	4·6	5·0	3·5	4·4	6,440	26	w.	11	4	4	2	6	19	23	18	14	0	14	7	9	9
Dec..........	1·59	0·52	22	74	67	70	70	4·8	6·7	3·7	5·1	5,945	26	nw.	27	7	2	4	4	14	24	17	19	2	9	15	7	11
Year..........	45·86	3·39	....	74	62	70	69	5·2	5·9	4·1	5·1	73,140	33	ne.	......	147	114	90	95	109	252	157	109	22	118	145	101	139

Meteorological summary, 1884.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.																
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A. M.	After-noon.	Night.	Monthly.						A. M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.220	.214	.236	.223	.74	26	8.57	13	1.17	16.6	23.0	17.9	19.2	26.5	11.1	15.4	18.8	49	30	—19	5	68	18	0	29
Feb	.120	.096	.114	.110	.57	15	8.52	19	1.05	24.8	30.5	27.7	27.7	35.4	20.3	15.1	27.8	53	19	— 3	29	56	8	0	25
Mar	.126	.099	.113	.113	.56	30	8.46	25	1.10	30.5	38.0	34.1	34.2	41.1	27.3	13.8	34.2	59	27	— 1	4	60	9	0	15
Apr	.059	.043	.054	.052	.48	21	8.38	15	1.10	41.1	47.4	44.4	44.3	50.7	37.9	12.8	44.3	77	30	31	2	46	0	0	1
May....	.065	.053	.055	.058	.49	29	8.61	1	.88	53.4	61.0	55.7	56.7	63.9	48.3	15.6	56.1	78	22	40	2	38	0	0	0
June ...	.182	.151	.155	.163	.40	14	8.81	9	.59	62.6	68.6	63.8	65.0	71.1	57.3	13.8	64.2	86	23	47	11	39	0	0	0
July ...	.059	.043	.039	.047	.32	20	8.77	5	.55	66.1	73.1	68.4	69.2	75.2	62.0	13.2	68.6	89	22	54	6	35	0	0	0
Aug....	.172	.150	.150	.157	.48	9	8.80	29	.68	64.5	73.3	68.5	68.8	74.9	61.7	13.2	68.3	91	19	51	10	40	0	1	0
Sept....	.159	.125	.134	.139	.54	13	8.64	24	.90	64.2	73.7	68.8	68.9	75.5	62.0	13.5	68.7	89	9	51	21	38	0	0	0
Oct.....	.244	.208	.220	.224	.64	14	8.91	5	.73	51.6	61.5	56.1	56.4	64.2	48.6	15.6	56.4	83	2	28	23	55	0	0	1
Nov	.176	.166	.180	.174	.56	6	8.50	23	1.06	35.5	44.0	39.3	39.6	48.8	33.1	15.7	41.0	64	9	5	24	59	2	0	9
Dec	.186	.169	.172	.176	.71	25	8.39	6	1.32	25.4	31.0	28.8	28.4	37.8	22.2	15.6	30.0	61	30	—11	19	72	10	0	20
Year ...	.147	.126	.135	.136	.74	....	8.38	....	1.36	44.7	52.1	47.8	48.2	55.4	41.0	14.4	48.2	91	....	—19	....	110	47	1	100

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	.01 rain-fall.
Jan	1.39	.39	1	72	67	67	69	6.2	6.1	3.9	5.4	6,713	26	w.	30	6	4	2	3	9	28	31	10	0	9	13	9	13
Feb..........	3.27	1.13	12	72	69	68	70	6.6	8.1	6.5	7.1	5,412	26	w.	19	4	16	5	5	16	7	16	17	1	4	11	14	16
Mar	5.16	3.20	25	72	63	68	68	6.6	6.9	6.1	6.5	6,168	28	sw.	11	19	12	10	5	13	7	12	13	2	4	11	16	15
Apr..........	3.05	1.74	15	75	59	69	68	5.9	6.9	4.8	5.9	6,364	36	w.	27	21	11	24	4	4	5	10	11	0	9	9	12	9
May..........	1.53	.68	1	72	57	68	66	4.8	5.6	3.3	4.6	6,016	25	nw.	27	24	7	10	9	16	17	6	11	0	9	17	5	10
June..........	2.11	.62	1	76	66	78	73	6.1	5.5	3.3	5.0	4,496	23	nw.	9	24	11	17	6	5	6	5	9	7	9	13	8	6
July	3.71	1.46	23	76	61	73	70	5.3	6.2	2.5	4.7	4,293	28	ne.	23	13	13	15	4	11	10	13	13	1	5	25	1	12
Aug..........	2.50	1.27	28	78	57	70	68	4.2	4.3	2.1	3.5	4,996	20	sw.	25	7	14	18	5	19	8	10	8	4	15	12	4	9
Sept..........	2.29	1.09	27	77	57	71	69	3.9	3.6	3.6	3.7	5,800	24	w.	17	7	8	14	4	22	21	12	2	0	15	9	6	8
Oct	3.59	1.39	7	77	60	71	69	4.4	5.1	3.1	4.2	5,745	35	n.	8	8	3	7	7	15	27	20	6	0	14	11	6	10
Nov.	1.80	.82	3	82	68	76	75	5.7	4.9	3.9	4.8	5,441	22	nw.	23	9	3	5	5	10	23	17	17	1	9	14	7	9
Dec..........	4.21	.93	28	83	76	80	80	8.1	7.2	6.9	7.4	6,574	29	sw.	31	0	4	2	9	21	19	19	19	0	4	9	18	18
Year..........	34.61	3.20	....	76	63	72	70	5.6	5.9	4.2	5.2	68,018	36	w.	......	142	106	129	66	161	178	171	129	16	106	154	106	135

Meteorological summary, 1885.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.212	.187	.183	.194	.77	2	8.30	6	1.47	14.6	22.1	18.3	18.3	27.5	9.6	17.9	18.6	50	9	—13	19	63	18	0	28
Feb	.093	.045	.088	.075	.64	23	8.50	4	1.14	12.4	20.8	17.1	16.8	26.8	8.8	18.0	17.8	47	3	—14	11	61	18	0	26
Mar	.149	.136	.174	.153	.50	10	8.57	14	.93	26.6	32.9	30.6	30.0	38.9	23.7	15.2	31.3	58	26	4	20	54	7	0	25
Apr	.126	.113	.107	.115	.42	13	8.65	10	.77	42.8	48.1	45.1	45.3	53.9	38.7	15.2	46.3	76	21	27	13	49	0	0	5
May	.039	.033	.034	.035	.29	15	8.65	5	.64	49.6	56.0	52.8	52.8	60.6	46.1	14.5	53.3	80	24	34	7	46	0	0	0
June ...	.148	.131	.146	.142	.41	30	8.72	7	.69	62.4	70.0	63.8	65.4	73.6	57.1	16.5	65.4	88	7	42	8	46	0	0	0
July ...	.109	.083	.091	.094	.34	18	8.87	14	.47	69.2	76.9	72.2	72.8	80.8	65.5	15.3	73.1	94	20	53	1	41	0	3	0
Aug	.111	.103	.105	.106	.43	26	8.73	2	.70	64.9	71.3	68.0	68.1	74.3	62.4	11.9	68.4	85	12	55	15	30	0	0	0
Sept....	.162	.139	.160	.154	.36	18	8.58	8	.78	60.1	67.8	63.8	63.9	70.6	58.3	12.3	64.5	81	21	47	6	34	0	0	0
Oct.....	.101	.076	.100	.092	.42	9	8.58	19	.84	47.1	55.0	50.9	51.0	57.6	45.5	12.1	51.6	69	2	36	30	33	0	0	0
Nov	.069	.056	.076	.067	.50	27	8.64	6	.86	39.3	44.4	41.9	41.9	48.7	36.7	12.0	42.7	66	6	28	14	38	0	0	4
Dec	.131	.108	.146	.128	.73	26	8.24	9	1.49	29.2	33.5	30.7	31.1	38.9	24.7	14.2	31.8	50	23	— 3	7	53	7	0	20
Year ...	.121	.101	.117	.113	.77	....	8.24	....	1.53	43.2	49.9	46.3	46.5	54.4	39.8	14.6	47.1	94	....	—14	....	108	50	3	108

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A.M.	Aftern'n.	Night.	Mean.	A.M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	3.18	1.24	5	78	67	77	74	4.2	5.7	4.6	4.8	7,316	22	sw.	26	5	5	3	2	16	32	22	8	0	10	13	8	11
Feb..........	2.01	.86	8	79	80	80	80	4.5	5.7	5.1	5.1	4,934	24	ne.	8	5	6	4	4	10	28	12	12	3	10	9	9	11
Mar	.57	.20	6	79	72	75	75	5.3	6.3	5.4	5.7	5,493	28	sw.	9	17	11	3	3	9	20	15	8	7	6	17	8	8
Apr..........	4.00	1.71	17	81	70	78	76	6.2	6.7	5.5	6.1	6,292	24	n.	2	18	12	15	6	14	7	7	9	2	3	19	8	16
May	3.17	1.23	29	76	63	74	71	5.2	5.1	4.4	4.9	5,406	30	sw.	8	23	13	9	10	8	12	9	6	3	11	13	7	11
June	5.20	3.44	2	78	60	75	71	4.8	5.3	3.3	4.5	4,649	24	n.	13	13	5	17	10	9	13	11	7	5	9	15	6	11
July..........	2.44	.83	9	80	65	77	74	4.3	4.6	2.5	3.8	4,233	26	n.	28	14	12	10	8	13	11	10	5	10	9	20	2	13
Aug..........	11.28	6.19	2	80	63	76	73	5.7	4.7	3.4	4.6	6,092	27	n.	2	16	13	14	9	9	14	9	9	0	8	18	5	13
Sept	2.97	1.65	8	77	64	75	72	4.7	4.8	4.0	4.5	5,726	25	s.	8	12	5	18	9	12	15	12	6	1	13	8	9	9
Oct	3.87	2.22	19	81	64	75	73	5.4	7.1	4.0	5.5	6,136	24	ne.	19	18	6	7	6	14	12	16	13	1	8	13	10	11
Nov	2.33	1.17	5	80	72	76	76	6.8	7.1	6.1	6.7	6,185	24	sw.	7	7	9	1	8	9	20	21	15	0	4	13	13	12
Dec..........	3.35	1.29	8	82	79	82	81	4.7	6.7	4.9	5.4	6,700	26	nw.	5	6	4	6	10	10	35	14	8	0	8	15	8	15
Year..........	44.37	6.19	....	79	68	77	75	5.2	5.8	4.4	5.1	69,162	30	sw.	......	154	101	107	85	133	219	158	106	32	99	173	93	141

Meteorological summary, 1886.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan....	.141	.115	.125	.127	.62	23	8.45	3	1.17	19.1	23.5	21.6	21.4	30.8	14.0	16.8	22.4	48	1	—14	....	62	17	0	28
Feb....	.131	.138	.175	.148	.71	4	8.46	25	1.25	24.7	31.1	28.5	28.1	38.9	19.9	19.0	29.4	56	9	— 6	....	62	8	0	23
Mar....	.170	.149	.154	.158	.62	2	8.18	20	1.44	32.8	39.2	36.4	36.1	44.2	30.1	14.1	37.2	70	19	15	....	55	3	0	17
Apr....	.155	.149	.162	.155	.55	19	8.44	1	1.11	46.6	52.7	48.0	49.1	57.3	42.1	15.2	49.7	81	23	23	....	58	0	0	5
May....	.089	.083	.071	.081	.44	17	8.72	9	.72	53.7	60.1	57.2	57.0	65.5	48.9	16.6	57.2	82	21	40	....	42	0	0	0
June...	.111	.098	.099	.103	.38	3	8.84	17	.54	63.7	69.3	65.1	66.0	73.7	58.7	15.0	66.2	87	15	49	....	38	0	0	0
July...	.125	.105	.095	.108	.31	1	8.87	13	.44	68.1	75.3	70.8	71.4	78.8	64.9	13.9	71.8	94	6	55	....	39	0	2	0
Aug....	.111	.097	.105	.104	.35	19	8.82	29	.53	68.8	76.3	72.0	72.4	78.7	66.5	12.2	72.6	92	21	53	....	39	0	1	0
Sept....	.184	.152	.165	.167	.44	18	8.84	30	.60	61.5	71.5	65.2	66.1	73.4	58.7	14.7	66.0	86	7	42	....	44	0	0	0
Oct.....	.292	.269	.293	.285	.66	16	8.33	14	1.33	51.7	61.4	56.8	56.6	64.7	49.3	15.4	57.0	79	12	32	....	47	0	0	0
Nov....	.126	.089	.105	.107	.52	15	8.47	23	1.05	34.3	42.2	38.0	38.2	46.2	30.5	15.7	38.4	69	2	16	....	53	3	0	16
Dec	.247	.221	.257	.242	.72	4	8.61	14	1.11	21.6	28.6	24.8	25.0	33.8	16.8	17.0	25.3	60	11	—10	....	70	13	0	27
Year ...	.157	.139	.150	.149	.72	....	8.18	....	1.54	45.6	52.6	48.7	49.0	57.2	41.7	15.5	49.4	94	....	—14	....	108	44	3	116

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
													Maximum.			Number of times blowing from—												
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	Clear.	Fair.	Cloudy.	Of rain-fall.
Jan	3.56	.71	15	84	79	88	84	6.1	7.1	6.1	6.4	7,498	28	w.	16	6	7	8	8	14	19	21	10	0	4	15	12	19
Feb	1.51	.53	11	81	69	81	77	6.6	6.2	3.9	5.6	6,895	29	sw.	25	1	4	5	10	17	20	17	10	0	5	16	7	9
Mar	1.79	.54	20	84	69	81	78	6.1	5.8	5.2	5.7	6,854	20	nw.	22	15	8	8	4	14	13	12	19	0	7	11	13	9
Apr	1.29	.42	29	87	76	86	83	5.7	5.5	3.7	5.0	6,148	30	nw.	6	17	7	7	17	8	13	4	17	0	8	13	9	10
May	1.00	.52	9	77	65	74	72	4.3	5.6	2.8	4.2	5,752	22	nw.	6	18	15	11	14	6	15	4	9	1	12	14	5	10
June	.94	.58	15	77	66	76	73	3.9	5.1	3.1	4.0	4,932	20	nw.	7	10	27	6	18	7	12	3	7	0	10	18	2	8
July	1.53	.61	13	75	62	74	70	3.4	3.2	1.3	2.6	5,472	23	ne.	7	16	24	14	11	8	8	7	5	0	18	11	2	6
Aug	3.38	1.39	28	79	64	75	73	5.2	4.7	3.5	4.5	5,432	24	nw.	16	9	17	17	17	12	8	9	4	0	8	19	4	11
Sept	6.93	2.11	9	80	59	76	71	4.9	5.4	3.4	4.6	5,543	22	nw.	18	3	5	6	22	19	16	12	7	0	11	11	8	13
Oct	1.42	.59	14	76	63	74	71	3.9	4.9	2.6	3.8	5,568	37	sw.	14	6	5	7	18	23	16	6	12	0	19	4	8	7
Nov	1.66	.74	16	83	71	76	77	5.2	5.4	5.0	5.2	6,924	32	sw.	18	8	0	9	1	23	18	23	8	0	10	10	10	10
Dec	1.76	.37	12	81	73	73	76	5.9	5.8	5.3	5.7	5,111	27	nw.	14	2	1	3	7	28	23	19	10	0	8	12	11	12
Year	26.77	2.11	....	80	68	78	75	5.1	5.4	3.8	4.8	72,129	37	sw.	......	111	120	101	147	179	181	137	118	1	120	154	91	124

Meteorological summary, 1887.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A. M.	After-noon.	Night.	Monthly.						A. M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.036	.031	.066	.044	.59	3	8.41	20	1.18	14.7	20.2	17.1	17.3	26.6	6.0	20.6	16.3	52	22	—15	3	67	19	0	30
Feb	.219	.206	.218	.214	.87	4	8.17	18	1.70	25.0	29.2	27.2	27.1	35.1	16.8	18.3	25.9	58	14	— 7	4	65	11	0	28
Mar	.171	.162	.180	.171	.70	4	8.57	24	1.13	28.8	34.0	32.8	31.9	39.4	24.9	14.5	32.1	68	12	9	28	59	6	0	27
Apr	.068	.048	.053	.056	.51	7	8.39	22	1.12	41.6	52.0	48.7	47.4	60.2	37.2	23.0	48.7	82	13	19	5	63	0	0	6
May....	.108	.099	.097	.101	.40	15	8.72	30	.68	56.5	63.5	58.2	59.4	68.7	51.0	17.7	59.8	86	20	42	6	43	0	0	0
June ...	.120	.103	.095	.106	.46	27	8.81	22	.65	63.5	71.3	67.0	67.3	75.8	58.8	17.0	67.3	96	17	48	10	48	0	2	0
July ...	.112	.091	.092	.098	.29	23	8.85	9	.44	71.8	80.4	75.7	76.0	84.2	66.5	17.7	75.3	100	16	61	21	39	0	5	0
Aug....	.144	.121	.121	.129	.35	30	8.87	22	.48	65.6	73.3	70.1	69.7	76.5	60.6	15.9	68.6	98	10	49	24	49	0	2	0
Sept . . .	.208	.187	.185	.193	.55	16	8.84	6	.71	58.8	66.3	62.5	62.5	70.2	54.5	15.7	62.3	92	6	38	23	54	0	1	0
Oct.....	.172	.143	.170	.162	.66	25	8.62	23	1.04	41.6	53.0	47.2	47.3	56.6	37.7	18.9	47.1	82	7	14	25	68	1	0	9
Nov	.157	.133	.177	.156	.84	30	8.38	19	1.46	34.8	41.2	38.1	38.0	46.0	26.9	19.1	36.4	67	3	— 1	29	68	2	0	19
Dec	.174	.135	.133	.147	.76	1	8.54	31	1.22	26.3	30.0	28.0	28.1	34.2	19.2	15.0	26.7	53	4	— 5	29	58	11	0	25
Year ...	.141	.122	.132	.132	87	....	8.17	....	1.70	44.1	51.2	47.7	47.7	56.1	38.3	17.8	47.2	100	....	—15	....	115	50	10	144

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
													Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan	3.13	1.39	22	79	79	79	79	6.5	5.2	7.4	6.4	9,248	33	w.	17	4	3	5	5	16	19	14	27	0	3	16	12	13
Feb..........	5.10	1.23	17	86	81	82	83	7.2	7.4	5.9	6.8	7,463	42	w.	26	2	7	14	4	9	20	17	11	0	5	6	17	17
Mar	.89	.48	5	79	70	75	75	5.7	6.0	4.0	5.2	8,271	35	n.	2	23	12	8	3	8	14	6	19	0	9	13	9	6
Apr..........	.46	.18	22	72	54	62	62	5.2	5.3	3.4	4.6	8,786	38	sw.	23	8	8	9	14	9	29	7	5	1	5	22	3	5
May..........	1.38	.49	30	74	60	70	68	4.2	4.2	3.0	3.8	6,915	44	sw.	2	19	21	11	12	9	14	4	3	0	15	8	8	9
June	1.63	.70	20	78	62	71	70	4.8	4.8	3.0	4.2	6,463	34	w.	18	10	16	15	13	3	17	10	6	0	12	13	5	7
July	1.05	.45	3	73	62	67	67	2.9	3.9	2.2	3.0	7,161	30	w.	17	12	19	12	12	10	19	9	0	0	18	11	2	10
Aug..........	3.35	1.24	13	75	61	67	68	5.0	3.7	3.7	4.1	6,579	30	nw.	10	14	21	23	13	2	3	6	8	3	14	10	7	9
Sept	4.03	1.33	21	79	63	73	72	6.4	6.2	5.2	5.9	7,849	36	e.	27	8	15	18	14	6	16	7	6	0	7	11	12	14
Oct	2.03	.82	22	82	61	69	70	5.6	5.6	3.4	4.9	9,025	44	w.	3	3	4	3	5	10	32	15	21	0	12	10	9	8
Nov..	2.41	.66	26	76	67	69	71	5.4	5.6	4.7	5.2	9,192	36	sw.	18	3	12	4	11	4	25	17	14	0	11	8	11	7
Dec..........	3.67	1.04	3	77	77	81	78	7.8	7.5	7.2	7.5	....	30	w.	4	2	8	8	11	3	35	16	10	0	4	7	20	13
Year.........	29.13	1.39	....	77	66	72	72	5.6	5.4	4.4	5.1	....	44	sw.	......	108	146	130	117	89	243	128	130	4	115	135	115	118

Meteorological summary, 1888.

Month.	Barometer reading (corrected for temp. and inst. error).									Temperature.															
	Mean.				Highest.	Date.	Lowest.	Date.	Range.	Mean.							Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	After-noon.	Night.	Monthly.						A.M.	After-noon.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min below 32°.
Jan	·301	·308	·318	·309	96	16	8.66	1	1·30	11·7	18·0	15·6	15·1	23·8	6·0	17·8	14·9	44	6	—17	16	60	23	0	30
Feb	·166	·129	·146	·156	89	15	8.40	25	1·49	19·7	25·6	23·8	23·0	30·9	14·1	16·8	22·5	47	20	—18	9	65	10	0	26
Mar	·209	·194	·219	·214	63	12	8.56	29	1·07	27·7	33·5	30·4	30·5	37·1	22·7	14·4	29·9	64	19	— 1	22	65	11	0	27
Apr	·278	·238	·244	·261	63	12	8.69	1	·94	40·9	50·1	45·1	45·4	55·7	37·1	18·6	46·4	83	28	30	3	53	0	0	6
May	·054	·039	·036	·045	41	20	8.69	27	·72	49·6	55·5	52·7	52·6	61·3	44·9	16·4	53·1	81	27	32	1	49	0	0	0
June ...	·073	·054	·051	·062	38	7	8.80	10	·58	63·6	71·5	67·1	67·4	75·7	58·8	16·9	67·2	90	20	43	2	47	0	0	0
July ...	·187	....	·139	·163	34	20	8.96	12	·38	70·6	....	73·4	72·0	80·6	64·6	16·0	72·6	94	31	56	13	38	0	3	0
Aug	·182	....	·151	·167	42	23	8.89	6	·53	66·7	....	71·6	69·2	76·7	61·9	14·8	69·3	91	3	51	23	40	0	1	0
Sept ...	·213	....	·171	·192	48	29	8.57	30	·91	56·4	....	62·9	59·6	66·7	52·9	13·8	59·8	88	11	36	29	52	0	0	0
Oct	·098	....	·084	·091	40	21	8.56	1	·84	45·5	....	51·2	48·4	55·9	42·3	13·6	49·1	76	31	32	20	45	0	0	1
Nov	·257	....	·230	·244	71	20	8.74	10	·97	38·8	....	43·0	40·9	47·1	36·0	11·1	41·6	75	1	20	17	55	1	0	7
Dec	·178	....	·174	·176	54	14	8.63	26	·91	29·7	....	32·9	31·3	38·0	26·6	11·4	32·3	53	26	15	28	38	6	0	24
Year ...	·183	....	·164	·173	96	....	8.40	....	1·56	......	....	....	....	54·1	39·0	15·1	46·6	94	....	—18	....	112	51	4	121

Month.	Rainfall.			Rel. humidity.				Cloudiness (0–10).				Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Aftern'n.	Night.	Mean.	A. M.	Aftern'n.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain fall.
													Veloc-ity.	Direc-tion.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan	1·56	·51	6	74	72	79	75	5·4	7·1	5·8	6·1	8,294	37	sw.	1	2	5	5	13	1	18	27	21	1	6	5	10	12
Feb..........	1·51	·76	24	80	72	76	76	4·7	6·5	3·2	4·9	7,702	45	s.	13	4	7	8	12	9	15	20	12	0	11	12	6	9
Mar	2·99	1·01	25	75	70	71	72	7·0	7·3	5·5	6·6	8,931	37	w.	21	6	25	8	8	5	13	17	11	0	7	11	13	12
Apr..........	2.13	·90	9	66	56	66	62	5·0	5·2	2·3	4·1	9,112	37	sw.	13	11	15	10	13	3	13	14	11	0	12	13	5	10
May	6.22	2·43	27	72	62	77	70	6·1	6·4	5·7	6·0	7,507	44	sw.	4	8	13	20	13	4	16	10	8	1	7	10	14	16
June..........	1·66	·97	27	71	58	69	66	4·4	6·3	3·4	4·7	7,383	30	sw.	13	7	18	12	11	9	18	11	4	0	8	17	5	8
July	3·93	1·29	31	69	....	67	82	3·5	......	5·7	4·6	6,450	39	ne.	12	7	16	10	6	6	9	6	1	1	11	8	12	11
Aug	2.10	1·00	2	69	....	62	66	4·5	......	4·1	4·3	7,730	40	nw.	2	9	11	8	5	1	18	9	1	0	9	11	11	9
Sept	·98	·45	16	69	....	62	66	3·4	......	2·6	3·0	6,670	27	n.	25	2	14	3	9	2	17	5	4	4	13	9	8	6
Oct	2·95	1·31	18	70	....	67	69	5·2	......	3·1	4·2	8,210	34	sw.	19	4	12	2	6	4	16	8	8	2	9	11	11	11
Nov	2·89	1·10	7	79	....	76	78	5·7	......	4·2	5·0	7,404	38	sw.	5	2	13	2	3	5	14	9	12	0	8	6	16	11
Dec..........	1·94	·89	25	84	....	79	81	6·5	......	4·6	5·6	8,360	41	s.	26	13	2	0	1	12	17	9	7	1	9	5	17	9
Year	30·86	2·43	....	....	....	....	....	......	......	......	......	93,753	45	s.	......	75	151	88	100	61	184	145	100	10	110	128	128	124

Meteorological summary, 1889.

Month.	Barometer reading (corrected for temp. and inst. error).								Temperature.														
	Mean.			Highest.	Date.	Lowest.	Date.	Range.	Mean.						Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	Night.	Monthly.						A.M.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.10	.11	.10	.55	19	8.09	9	1.46	25.8	30.9	28.4	35.0	23.0	12.0	29.0	55	16	zero	21	55	11	0	28
Feb	.23	.20	.21	.89	23	8.42	4	1.47	16.3	21.9	19.1	26.8	13.0	13.8	19.9	48	4	—11	23	59	16	0	27
Mar	.13	.11	.12	.46	22	8.79	6	.67	34.3	39.2	36.8	44.7	32.1	12.6	38.4	68	16	20	9	48	2	0	11
Apr	.15	.11	.13	.62	7	8.76	12	.86	44.0	47.1	45.5	52.9	40.7	12.2	46.8	73	20	29	6	44	0	0	1
May	.09	.05	.07	.31	4	8.78	27	.53	52.4	57.0	54.7	64.5	49.1	15.4	56.8	88	8	36	2	52	0	0	0
June ...	.11	.09	.10	.48	24	8.75	7	.73	59.9	62.5	61.2	69.5	55.1	14.4	62.3	86	19	42	1	44	0	0	0
July ...	.13	.10	.11	.31	16	8.79	27	.52	68.5	71.6	70.0	77.2	63.8	13.4	70.5	90	9	54	15	36	0	0	0
Aug	.23	.19	.21	.39	6	8.92	13	.47	66.4	72.7	69.6	77.8	63.3	14.5	70.5	88	29	54	6	34	0	0	0
Sept....	.17	.13	.15	.49	27	8.75	20	.74	58.2	64.8	61.5	69.9	55.7	14.2	62.8	84	14	35	27	49	0	0	0
Oct.....	.26	.24	.25	.60	23	8.76	25	.84	45.7	51.6	48.7	55.2	43.5	11.7	49.3	79	11	35	8	44	0	0	0
Nov	.18	.18	.18	.69	16	8.61	21	1.08	35.9	39.5	37.7	41.3	34.0	7.3	37.6	57	1	12	30	45	3	0	11
Dec	.17	.16	.16	.63	30	8.47	29	1.16	37.9	41.8	39.9	47.2	34.1	13.1	40.6	64	24	15	30	49	1	0	7
Year ...	.16	.14	.15	.89	......	8.09	......	1.80	45.4	50.0	47.7	55.2	42.3	12.9	48.7	90	....	—11	....	101	33	0	85

Month.	Rainfall.			Rel. humidity.			Cloudiness (0-10).			Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A.M.	Night.	Mean.	A.M.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rainfall.
											Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan	1.64	.68	8	84	81	82	5.2	3.9	4.6	7,807	44	sw.	17	2	3	5	4	1	25	7	12	3	10	8	13	5
Feb	1.31	.44	15	84	81	82	7.5	3.6	5.6	7,394	32	sw.	19	1	4	2	2	4	13	15	14	1	4	13	11	13
Mar	1.43	.93	30	81	71	76	5.0	4.2	4.6	7,985	40	n.	18	12	12	2	7	0	6	12	10	1	9	15	7	5
Apr	2.35	1.03	11	77	74	76	4.2	5.4	4.8	7,936	36	sw.	24	5	15	9	9	2	10	3	7	0	10	9	11	8
May	5.38	1.42	10	72	70	71	4.9	7.3	6.1	9,771	48	n.	31	15	15	1	2	9	10	3	6	1	4	15	12	14
June	2.93	.68	16	82	76	79	4.8	7.8	6.3	5,614	28	nw.	19	8	11	5	6	4	13	8	4	1	1	13	16	12
July	9.56	4.02	27	75	70	72	3.5	4.9	4.5	5,979	36	sw.	27	4	13	10	5	3	16	5	6	0	14	8	9	12
Aug	.39	.16	8	68	63	66	2.7	3.6	3.7	5,290	25	sw.	8	3	10	3	7	8	20	5	5	1	15	11	5	7
Sept	2.75	2.08	4	74	64	69	5.8	3.4	5.4	5,609	28	nw.	17	2	7	4	9	8	13	3	12	2	8	11	11	7
Oct	1.82	.82	12	74	66	70	6.2	4.4	4.9	7,096	32	ne.	25	9	12	5	8	5	8	3	12	0	14	7	10	7
Nov	3.49	1.47	1	86	80	83	7.3	5.8	6.9	7,488	37	w.	28	4	9	5	5	4	16	2	14	1	5	9	16	17
Dec	1.90	.95	9	78	74	76	6.6	5.6	5.9	7,664	36	nw.	29	2	3	3	11	3	24	8	7	1	10	9	12	10
Year	34.95	4.02	....	78	72	75	5.3	5.0	5.3	85,633	48	n.	......	67	114	54	75	51	174	74	109	12	104	128	133	117

Meteorological summary, 1890.

Month.	Barometer reading (corrected for temp. and inst. error).								Temperature.															
	Mean.			Highest.	Date.	Lowest.	Date.	Range.	Mean.						Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A. M.	Night.	Monthly.						A. M.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan	.37	.36	.36	.94	3	8.54	12	1.40	28.6	33.3	30.9	38.0	23.7	14.3	30.8	62	12	— 5	22	67	9	0	21
Feb	.17	.15	.16	.57	21	8.70	19	.87	29.2	34.2	31.7	38.7	26.2	12.5	32.4	59	4	3	21	56	6	0	20
Mar	.18	.17	.18	.61	8	8.50	28	1.11	25.3	31.3	28.3	35.7	23.3	12.4	29.5	56	21	zero	1	56	9	0	24
Apr	.23	.19	.21	.62	20	8.60	8	1.02	42.9	45.9	44.4	52.8	38.4	14.4	45.6	75	30	28	14	47	0	0	3
May....	.05	.02	.04	.48	11	8.69	18	.79	50.0	55.1	52.6	61.5	45.2	16.3	53.3	86	30	34	1	52	0	0	0
June...	.13	.08	.10	.48	8	8.85	5	.63	67.9	71.3	69.6	77.6	62.7	14.9	70.1	92	28	52	8	40	0	1	0
July ...	.16	.13	.14	.38	16	8.88	1	.50	69.6	74.1	71.8	78.9	65.3	13.6	72.1	93	7	56	25	37	0	4	0
Aug....	.21	.17	.19	.46	23	8.94	26	.52	64.4	69.0	66.7	73.7	61.4	12.3	67.5	96	2	51	22	45	0	2	0
Sept....	.25	.21	.23	.57	28	8.91	12	.66	57.0	63.0	60.0	66.8	54.0	12.8	60.4	88	6	39	13	49	0	0	0
Oct.....	.07	.06	.06	.32	21	8.58	28	.74	49.2	52.1	50.7	56.6	46.1	10.5	51.3	73	9	28	31	45	0	0	2
Nov	.17	.17	.17	.52	22	8.83	1	.69	37.8	43.8	41.3	48.7	35.1	13.6	41.9	67	5	27	3	40	0	0	7
Dec	.21	.19	.20	.55	25	8.72	10	.83	27.7	31.7	29.7	36.6	24.5	12.1	30.5	53	30	8	4	45	10	0	25
Year ...	.18	.16	.17	.94	......	8.50	......	1.44	45.8	50.4	48.1	55.5	42.2	13.3	48.8	96	....	— 5	....	101	34	7	102

Month.	Rainfall.			Rel. humidity.			Cloudiness (0–10).			Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Night.	Mean.	A. M.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rainfall.
											Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	2.98	.94	3	84	78	81	6.7	5.5	5.9	7,978	42	nw.	8	5	2	1	7	6	19	10	12	0	7	13	11	14
Feb..........	2.42	.53	7	85	78	82	6.8	5.5	6.5	12,105	48	w.	5	1	12	3	7	3	13	7	10	0	7	6	15	12
Mar	2.10	.60	11	79	70	74	5.5	4.8	5.1	13,806	68	ne.	27	5	11	5	8	3	8	7	15	0	9	13	9	15
Apr..........	3.23	.90	13	74	70	72	4.7	4.9	4.6	14,912	56	sw.	12	4	26	7	6	7	5	2	3	0	13	9	8	12
May.	5.13	2.60	9	78	64	71	5.7	6.2	6.1	13,538	59	ne.	10	1	15	3	8	5	15	7	8	0	8	10	13	16
June	3.25	1.03	10	76	70	73	5.6	5.6	5.1	9,225	53	sw.	5	3	13	5	11	6	11	9	2	0	8	17	5	14
July	2.57	1.31	14	66	61	64	3.8	3.9	3.5	11,503	52	ne.	4	3	13	4	13	6	14	4	4	1	13	17	1	5
Aug..........	2.58	1.47	20	76	71	74	5.5	4.8	4.7	10,297	45	s.	8	4	16	7	10	6	11	4	4	0	12	10	9	10
Sept.	1.39	.98	7	79	72	76	6.0	4.6	5.1	12,436	49	nw.	19	6	13	6	10	7	10	3	5	0	9	12	9	7
Oct	4.20	1.16	25	86	77	82	6.7	5.7	7.0	10,751	50	sw.	13	8	7	4	9	6	10	2	15	1	4	9	18	15
Nov	1.59	.84	16	80	66	73	4.8	6.5	5.3	12,224	45	sw.	5	3	5	4	4	3	16	13	12	0	11	7	12	8
Dec..........	1.25	.47	31	80	73	76	7.0	4.1	5.3	13,582	54	sw.	13	10	4	2	8	5	12	10	10	1	10	10	11	8
Year.........	32.69	2.60	....	79	71	75	5.7	5.2	5.4	142,357	68	ne.	......	53	137	51	101	63	144	78	100	3	111	133	121	136

Meteorological summary, 1891.

Month.	Barometer reading (corrected for temp. and inst. error).								Temperature.														
	Mean.			Highest.	Date.	Lowest.	Date.	Range.	Mean.						Mean max. and min.	Highest.	Date.	Lowest.	Date.	Absolute range.	Number of times—		
	A.M.	Night.	Monthly.						A.M.	Night.	Monthly.	Max.	Min.	Range.							Max. below 32°.	Max. above 90°.	Min. below 32°.
Jan....	.16	.16	.16	.75	8	8.29	1	1.46	28.3	30.5	29.4	35.0	25.4	9.6	30.2	54	1	10	13	44	9	0	25
Feb....	.12	.10	.11	.60	14	8.34	24	1.26	24.7	30.7	27.7	35.7	21.5	14.2	28.6	58	24	— 8	4	66	9	0	23
Mar....	.15	.12	.14	.59	1	8.63	31	.96	27.5	32.2	29.8	36.2	25.1	11.1	30.6	57	17	7	4	50	10	0	24
Apr....	.14	.11	.12	.40	28	8.86	2	.54	44.5	47.9	46.2	53.9	40.0	13.9	47.0	75	26	23	4	52	2	0	5
May....	.26	.20	.23	.55	5	8.96	31	.59	51.2	54.7	53.0	61.1	45.7	15.4	53.4	81	9	35	4	46	0	0	0
June...	.09	.05	.07	.37	5	8.70	18	.67	63.2	66.1	64.6	72.2	59.2	13.0	65.7	88	25	44	4	44	0	0	0
July...	.18	.14	.16	.41	9	8.94	29	.48	64.9	68.7	66.8	73.4	60.5	12.9	67.0	87	12	55	5	32	0	0	0
Aug....	.14	.11	.12	.30	28	8.77	20	.53	66.2	70.5	68.4	75.5	62.5	13.0	69.0	96	9	49	28	47	0	3	0
Sept....	.27	.22	.25	.49	9	9.00	28	.49	64.4	70.7	67.6	76.0	62.1	13.9	69.0	91	24	48	29	43	0	1	0
Oct.....	.23	.22	.22	.58	27	8.94	14	.64	47.7	54.5	51.1	60.0	45.1	14.9	52.6	86	2	33	22	53	0	0	0
Nov....	.17	.17	.17	.72	18	8.60	10	1.12	31.1	35.4	33.2	39.4	28.2	11.2	33.8	60	7	3	29	57	7	0	17
Dec....	.16	.13	.14	.74	11	8.49	3	1.25	32.3	37.0	34.6	41.6	29.1	12.5	35.4	57	14	9	26	48	4	0	16
Year...	.17	.14	.16	.75	......	8.29	......	1.46	45.5	49.9	47.7	55.0	42.0	13.0	48.5	96	....	— 8	....	104	41	4	110

Month.	Rainfall.			Rel. humidity.			Cloudiness (0-10).			Wind.													Number of days—			
	Total.	Greatest in any 24 hours.	Date.	A. M.	Night.	Mean.	A. M.	Night.	Mean.	Total.	Maximum.			Number of times blowing from—									Clear.	Fair.	Cloudy.	.01 rain-fall.
											Velocity.	Direction.	Date.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.				
Jan..........	1.99	1.25	1	85	79	82	7.2	6.4	7.1	11,142	54	ne.	2	4	7	4	7	6	13	9	12	0	3	9	19	11
Feb..........	1.95	.99	19	82	79	81	5.6	5.5	5.5	13,357	60	sw.	24	5	3	4	7	4	13	13	7	0	10	8	10	12
Mar..........	2.13	.58	30	84	84	84	7.8	7.2	7.7	14,319	56	sw.	15	3	19	8	11	0	9	8	4	0	2	12	17	15
Apr..........	3.14	1.48	9	80	70	75	5.4	5.6	5.2	12,043	50	se.	20	11	12	3	9	4	8	8	5	0	10	10	10	15
May..........	2.09	.84	22	71	62	67	4.5	5.1	4.1	11,865	51	s.	9	9	23	1	11	3	11	3	0	1	14	10	7	7
June........	2.42	.79	28	82	80	81	4.5	5.3	5.6	9,961	45	e.	6	3	21	7	11	7	3	2	5	1	7	12	11	11
July........	2.47	1.28	6	74	66	70	3.1	4.0	3.9	9,670	50	ne.	2	3	10	4	9	7	14	6	7	2	13	13	5	8
Aug..........	4.52	1.92	23	77	72	74	3.7	6.2	4.7	9,228	48	ne.	23	4	12	3	9	5	15	4	9	1	10	14	7	10
Sept..........	.32	.20	2	68	64	66	3.1	2.3	2.2	10,184	40	sw.	28	3	7	2	10	10	14	7	5	2	20	9	1	4
Oct..........	.36	.21	6	73	60	67	5.9	2.6	4.3	12,899	46	ne.	26	5	5	2	8	10	12	6	13	1	13	11	7	5
Nov..........	3.83	.84	8	81	77	79	7.5	6.3	7.2	14,425	51	s.	19	4	9	0	6	11	8	14	8	0	6	5	19	11
Dec..........	1.32	.56	6	78	76	77	6.4	5.2	5.2	15,935	57	se.	1	2	5	0	12	16	16	9	2	0	11	9	11	9
Year..........	26.54	1.92	....	78	72	75	5.4	5.1	5.2	145,028	60	sw.	......	56	133	38	110	83	136	89	77	8	119	122	124	118

TABLE LIX.—*Mean monthly dew-point.*

Month.	1883.				1884.				1885.				1886.				1887.				1888.			
	A. M.	P. M.	Night.	Mean.	A. M.	P. M.	Night.	Mean.	A. M.	P. M.	Night.	Mean.	A. M.	P. M.	Night.	Mean.	A. M.	P. M.	Night.	Mean.	A. M.	P. M.	Night.	Mean.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	9	10	8	9	9	14	9	10	15	18	18	17	9	12	12	11	9	15	12	12	5	10	10	8
February	11	15	15	14	17	21	18	19	19	22	23	21	7	16	12	12	21	24	22	22	14	18	17	16
March	18	18	19	19	23	26	24	24	28	30	31	30	21	25	24	23	23	25	26	24	20	24	22	22
April	33	33	34	33	33	33	34	33	43	45	44	44	37	38	39	38	33	34	35	34	30	33	33	32
May	42	41	42	42	44	45	44	44	46	48	48	47	42	42	44	43	48	48	48	48	41	42	45	43
June	54	55	55	55	55	56	56	56	56	56	57	56	55	55	56	55	56	56	56	56	54	55	56	55
July	59	60	61	60	58	58	59	58	60	60	62	60	63	64	64	64	62	65	63	63	60	......	61	60
August	56	57	58	57	57	56	58	57	62	62	63	62	58	57	60	58	57	58	58	57	56	......	57	56
September	49	49	51	50	57	57	59	57	55	55	57	56	53	54	55	54	52	52	53	52	46	......	48	47
October	42	42	42	42	45	47	46	46	44	48	48	47	41	42	43	42	36	39	36	37	36	......	40	38
November	29	32	31	31	30	34	32	32	29	32	31	31	33	35	34	34	27	30	28	28	32	......	36	34
December	19	24	21	21	21	24	23	23	17	21	17	18	24	28	26	26	20	23	23	22	25	......	27	26
Year	35	36	36	36	37	39	39	38	40	41	42	41	37	39	39	38	37	39	38	38	35	......	38	36

TABLE LX.—*Grains per cubic foot of moisture in the air.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
1882	1.53	2.07	2.16	2.55	3.08	4.98	5.20	6.41	4.83	3.89	2.33	1.24	3.36
1883	.81	.98	1.22	2.23	3.04	4.86	5.76	5.17	4.05	3.10	2.01	1.39	2.88
1884	.86	1.23	1.56	2.23	3.35	5.00	5.45	5.27	5.27	3.54	2.13	1.46	3.11
1885	.88	.90	1.48	2.66	3.18	4.87	6.50	5.45	4.70	3.10	2.32	1.67	3.14
1886	1.14	1.38	1.94	3.28	3.73	5.12	5.86	6.26	5.00	3.65	2.04	1.20	3.38
1887	.90	1.44	1.57	2.28	3.80	5.04	6.44	5.27	4.40	2.57	1.85	1.42	3.08
1888	.78	1.10	1.43	2.14	3.15	4.85	5.84	5.13	3.64	2.66	2.29	1.67	2.89
1889	1.51	1.02	1.91	2.62	3.37	4.73	5.83	5.24	4.20	2.74	2.19	2.18	3.13
1890	1.67	1.67	1.35	2.38	3.08	5.76	5.38	5.20	4.38	3.43	2.13	1.47	3.16
1891	1.54	1.42	1.61	2.66	2.97	5.38	5.03	5.57	4.86	2.76	1.74	1.82	3.11
Mean	1.16	1.32	1.62	2.50	3.28	5.06	5.73	5.50	4.53	3.14	2.10	1.55	3.12

TABLE LXI.—*Dates of first and last killing frosts at Chicago.*

Year.	First.	Last.	Year.	First.	Last.
1873	Oct. 23	....	1883	Oct. 1	Apr. 24
1874	Oct. 31	Apr. 24	1884	Oct. 23	Apr. 2
1875	Oct. 2	May 2	1885	Sept. 17	May 10
1876	Oct. 4	Apr. 30	1886	Nov. 8	May 21
1877	Oct. 22	Apr. 30	1887	Oct. 11	Apr. 25
1878	Oct. 19	May 13	1888	Oct. 3	May 15
1879	Oct. 20	Apr. 3	1889	Sept. 27	Mar. 30
1880	Oct. 18	Apr. 12	1890	Oct. 27	Apr. 14
1881	Oct. 19	Apr. 7	1891	Oct. 22	Apr. 8
1882	Nov. 3	May 25	1892	....	Apr. 24

ABSTRACT OF DAILY JOURNAL, CHICAGO, ILL.

1870.

November 25.—Slight aurora.

November 30.—One certain forerunner of all storms here seems to be a strong current of air from the west or southwest, in the former case swerving by the north, in the latter by the south. In the former case the storm will attain its maximum when the wind reaches the northeast, in the latter when it reaches the southeast and east.

1871.

February 24.—The wind of to-day was the most violent that has been experienced at Chicago since November, 1860. Its rise and fall were equally sudden. At 7 a. m. its velocity was 26 miles; at 10 a. m., 32 miles; at 12.15 p. m., 48 miles; at 3 p. m., 32 miles; at 4 p. m., 21 miles per hour. This storm, and that of January 13, go to prove that the Rocky Mountains do not, as has been generally supposed, prevent meteorological conditions from acting on their movements.

March 18.—There was a considerable auroral display to-night.

April 9.—An aurora was visible at 7 p. m. Increasing in brilliancy, at 9 p. m. it exhibited the most magnificent auroral display which has been witnessed in Chicago since this office was opened. It consisted of the usual streamers and dark band underneath.

April 13.—At 9.15 p. m. the aurora divided itself into two distinct parts, and a band resembling a curtain, and extending from one horizon to the other, rose to about 55°. At 9.35 p. m. this separated portion had risen so high that its lower part was at the pole star. The whole was in rapid motion from east to west. There was very little of that shooting motion sometimes so marked.

May 16.—Rain commenced at 5.15 p. m., accompanied with thunder. At this time a cloud of intense blackness, brilliantly illuminated with lightning, hung over the southern portion of the city, and a tornado of great fury for this latitude passed over Bridgeport (a southern suburb), causing considerable loss of life and property. Only the outskirts of the storm passed over the city. The force of the wind may be illustrated by the newspaper report that it lifted a house, carried it 300 yards, and deposited it in a ditch.

May 25.—Thunderstorms traveling about all day. To-day has well illustrated what, from the experience of the past few weeks, appears to be a fact. Cumulus clouds, whether discharging rain or not, which approach the lake from the land grow developing, or at least maintain their proportions until they reach the margin of the lake. Then they dissipate, and what an hour before was a dense cloud becomes reduced to a few filaments. Day after day, with the cumulus clouds traveling from the southwest, have I seen them standing about like giants over all the land and around the shores of the lake, while over the lake the sky was entirely free of cumulus clouds.

June 23.—The rain commenced at 7.15 p. m. At 7.20 a hurricane sprang up from the northwest; this continued till 7.40, doing considerable damage to trees and houses. The rain during this time, combined with the spray, presented very much the appearance of a snowstorm, so dense was it. At 7.45 p. m. the rain nearly ceased; the amount which had fallen between 7.15 and 7.45, as measured by the Signal Service rain gauge, was 1.93 inch.

July 14.—A brilliant aurora manifested itself a little before 11 p. m. The streamers and dark cloud beneath were exceptionally well defined. There was very little apparent lateral or perpendicular motion. The height of the highest part was about 50°, and the height of the lowest extremities of the streamers about 20°. It presented at 11 p. m., when brightest, very much the appearance of a curtain.

July 15. The temperature rapidly rose till noon, when it marked 85°; a northeast wind then sprang up, and at 4 p. m. the temperature had fallen to 73°. During the time that this cooling process was going on, a severe storm kept moving along the southern horizon. A slight shower occurred here. The storm evidently took place when the northeast wind which had sprung up at noon met the southwest wind which it was displacing. This cool Arctic current, as shown by the p. m. reports, came down over the whole Lake country simultaneously. This rapid cooling, from the north, produced great differences of temperature within very limited areas. At 4 p. m. the temperature was 72° at Indianapolis, while at Saint Louis it was 100°. At New York the temperature was 73°, at Baltimore 93°; at both Indianapolis and New York great storms took place. The barometer in neither case showed unusual symptoms.

July 21—Aurora during the evening. The brightness was not strongly distinguished from the darkness, but long bands of darkness, apparently caused by bands of this cirrus cloud, stretched into the brightness.

July 22.—Slight aurora, consisting of bright isolated streamers without any other auroral accompaniment, shading far up into the sky.

July 23.—Very cool for the season. Since the 18th the thermometer has not reached 70° till to-day. From the evidence of this month alone, it could be held that auroras herald and accompany cold weather.

July 26.—At 3.40 p. m. rain commenced; the wind changed from southwest to northwest at 3.50 p. m. and from northwest to northeast at 4 p. m. During a few minutes before 4 p. m. large hail of about three-quarters of an inch in diameter fell scatteringly amid the rain. The outskirts of the shower only touched the observer's office, but to the north and northeast a severe hailstorm took place, breaking a large amount of window glass. At 7 p. m. a heap of hail 1½ feet deep lay beside a church in the northern part of the city. The hailstones were remarkably smooth and regular. A mile south, I understand, there was neither rain nor hail. The storm was wholly caused by the cold northeast wind coming into antagonism with the warm southeast wind. From the roof one could see, by the smoke, that the extent of the storm was precisely the same as that of the northeast wind. That this violent storm was wholly produced by the contact of masses of air of very different degrees of temperature, and *not* by any differences of pressure, is shown by the fact that the thermometer fell from 84° at 3.58 to 70° at 4.05 p. m. The barometer had been falling somewhat, but manifested no unsteadiness on thus suddenly passing into a much colder stratum of air. The clouds from which the hail fell were of great elevation. The sky had been remarkably transparent during the day, rendering the sun's rays exceedingly powerful.

July 31.—The month just gone is spoken of by everyone as being one of the coldest ever experienced in Chicago.

August 10.—At 11.15 p. m. a flash of lightning struck directly over the city, dividing, as it did so, into a great many branches. The report was instantaneous, and consisted of a sharp, cracking sound. As soon as the cloud came over Lake Michigan the discharges between it and the earth became much more frequent—almost continuous—the flashes descending in a nearly perpendicular stream.

August 11-12, 23.—Slight auroras.

August 26.—Cloudy day, with wind from northeast. Northeast is supposed to be the rainy direction here. This is undoubtedly the case during the spring and winter, but now, since the atmosphere is cooling and the lake warm, it is not so much so.

August 31.—From the 13th onward the thermometer only reached 80° on two days, and on two days it did not reach 70°. The coolness has been undeniably due to the prevalence of northeast winds. Thirty-two of the 156 observations were northeast and 25 were east. Even an easterly wind gets considerably cooled by passing over the lake. The northerly winds have been almost invariably accompanied or preceded by auroras.

September 5.—Warm day, 87°. Cirrus and cirro-cumulus clouds during the afternoon from west-southwest. A very bright auroral display took place during the evening.

October 16.—Took possession of new office, No. 10 W. Randolph street, yesterday. Have been without records from October 8 until to-day, everything official having been destroyed by the great fire, October 8 and 9. The observation at 10.53 p. m., October 8, was taken and transmitted as usual. At half past 9 an alarm of fire was rung. There had been a very large fire the preceding night, which was subdued with difficulty. The weather was intensely dry, and the wind blowing from the south-southwest with a velocity of about twenty miles per hour. Accordingly when by 10 o'clock p. m. the fire had increased instead of diminishing, many people turned out to see it, not from alarm, but simply for the sake of the spectacle. At 10.30 the fire was still confined to two blocks, with a strong hold of only one. The firemen at this time seemed to have a fair chance of checking it, still the burning was so great as to enable one, by the light of it, to read the time on the city clock, one and a half miles distant. The wind was carrying the sparks right through the center of the city, the line lying only two blocks west of the city hall. Still no one felt alarmed, except those in the immediate vicinity. I myself was present, and had seen the much larger fire of the preceding night checked by the river. By 12 p. m. the fire had increased considerably in area and intensity, but as the wind was south-southwest, and the river ran due north and south, there seemed as yet but little danger for anything beyond the river. Hitherto the fire had been propagated, and with no great velocity, merely by contact with the flames, but toward 1 a. m. the heat had become so intense as greatly to increase the power of the wind in the immediate neighborhood of the flames. This was especially the case on the east and west of the fire toward the front, the wind blowing straight toward the fire in all directions. Within forty yards of the blaze I estimated the wind blowing from the east toward it at thirty miles per hour. This caused a decided whirling motion in the column of flame and smoke, which was contrary to the hands of a watch.

Blazing pieces of timber of considerable size were now whirled aloft and carried to the north-northeast, starting new fires as they fell. These new fires being in the line of the smoke were invisible to those at the old fire. One of the fires was on the east side of the river, only a few blocks from the courthouse. By 2 o'clock the courthouse, with all the beautiful buildings around it, was in flames. The conflagration was now proceeding in the line of the wind as fast as a man could walk. By 3 a. m. the waterworks, two miles to the northeast of the courthouse, were burned. The city having thus been divided in two by a sheet of flame, the fire continued to work its way more leisurely to the east and west at right angles to the wind, as well as right in the teeth of it. The fire on the night of the 7th alone saved the west division. It had burned two blocks in breadth down the west side of the river. The fire on the 8th originated only a few blocks further south, hence it could not progress north for want of material. On the east side of the river, in the south division, the fire continued to work toward the east; this it did with the greatest rapidity at the southern limit of the conflagration, because there the unburned houses broke the wind and caused a back current at the base of the buildings. As soon as the fire had thus got a new swath of houses before it, and the wind behind it, away it went tearing, thus sadly surprising many who were congratulating themselves because the first rush of flame had spared them.

The Tribune people thought the strength of their building had saved them, because it lay at the extremity of one of the swaths. The next one took it. In the north division the first rush of the fire reached the lake, and then worked its way westward to the river. This it did not accomplish before 12 noon on the 9th. The wind had by 9 a. m. increased to perhaps twenty-five miles per hour, at the distance of three miles to the southwest of the fire. In the immediate vicinity of it, and especially in the streets running east and west, it was blowing with the force of a hurricane, lifting up on the north side whole burning wooden buildings and pitching them on the tops of others. The wind, blowing in all directions toward the fire, confused some people in their endeavors to escape. This also caused the fire to progress along the tops of the buildings before the wind, and along the bases against the wind. The heat was intense. The buildings in front and at the sides of the fire began first to smoke from the heat radiating from the burning. Then, in many cases, without waiting for a tongue of flame to touch them, they would all at once burst into a blaze. To talk of fireproof buildings in the midst of such a furnace is absurd. Steel was melted in innumerable cases, and stones and brick were burned to powder.

The firemen at first endeavored to check the fire in front. As soon as the fire had gathered in force this was not even to be thought of; not a single drop of water could reach the fire. The wind swept it aloft; besides, the firemen had to look out. Several of the engines which went to the front at first got burnt; others made futile efforts along the side of the fire, playing at right angles to the wind. The fire ate in behind them, and they had to run. I saw several engines, before the water stopped, doing nothing. At length they saw what they could do, and confined themselves to that. Letting the fire have free scope to the north and east, they endeavored to prevent it from spreading south against the wind. In this they succeeded, cutting it off just as it was preparing to lay hold of immense piles of lumber which lay along the river. This was done about 3 a. m. Monday. The efforts of the firemen, lamed for want of water, were ably seconded by gunpowder in the forenoon in the southern division. The same agent had been employed to check the northward progress of the fire, but in vain. Toward noon the further progress of the fire southward was thus checked. In the northern division it had reached its limits about the same time, having burnt everything that would burn, out as far as Lincoln Park, about four miles from the courthouse.

The loss of life was greatest along the path of the first rush of fire; it came so sudden and unexpected. Only those who died in the streets have been recovered. The very bones of those who were in the buildings would be burned.

The observation-office lay right in the path along which the conflagration mowed its first swath, from the southwest through the center of the city to the northeast. I went to the scene of the fire between 10 and 11 p. m., and did not think of the danger until too late. Kaufman was on duty, and saved the most valuable of the instruments, but only for a time. He carried them to his lodgings, which lay nearer the lake, and returned to find all the buildings around the office in a blaze. Thinking himself safe, he went back to his lodgings and went to sleep, and awoke in time to find the flames just upon him. Snatching his trunk, he escaped to the lake. Many trunks were lying there in flames, and he pitched his into the water. It might have been possible to have saved everything by procuring a vehicle at first; but vehicles were scarcely to be had. A jeweler, only a block from the observation-office, is said to have offered a thousand dollars for one in vain.

December 8.—Isolated snowflakes of very perfect and beautiful forms continued to fall all day without the slightest appearance of cloud. This caused an apparent haze which, however, extended to no great height in what was otherwise a very clear sky. It struck one that the snow might be caused by the cooling of the unduly heated air over the city. This hazy appearance, which was of different degrees of density, sometimes produced a halo and parhelia. Similar phenomena were witnessed here last winter. During the evening there was an aurora of considerable brightness, but only faint traces of streamers.

December 12.—One of the reasons why cyclones take a northeasterly course generally in these latitudes must be the following: On the east side of the storm the wind blows from a southerly direction, thus bringing the warm, moist air of the south on the east ot the cyclone. On the west of the storm, on the contrary, the dry, cold north wind blows. As the storm, other things being equal, must move in the direction of least resistance it must necessarily move towards the highest temperature and greatest moisture, which lie towards the east and north, being carried there by the south wind.

December 16.—A slight aurora, consisting entirely of diffused light and extending only a few degrees above the horizon.

December 24.—The barometer at 8.30 a. m. reached 28.50, attached thermometer 62°, and exposed 44°, which, I believe, is the lowest which has been reached at this station. It continued nearly stationary till noon, when it began to rise rapidly. At 2.15 p. m. it could be observed creeping up with the naked eye. The temperature at the same time fell rapidly as the wind changed from south and southwest to west. At noon it was 49°; at 2 p. m. it had fallen to 32°.

1872.

January 19.—At night, even when snowing pretty heavily, the moon and stars could be plainly seen as through a haze. Frequently there seemed to be no clouds at all; at other times light clouds were seen scudding rapidly across the moon from the north, the wind meanwhile blowing from the west. That a cold current was aloft at no great height was shown by the fact that notwithstanding it snowed all day the thermometer continued above the freezing point.

January 20.—The same phenomenon occurred to-day as yesterday, only at night the thermometer fell below the freezing point. It seems that this snowing or raining with a clear sky (or almost so) occurs when a cold current of air flows over the warm. When the cold current flows under the warm, dense clouds result. All these little snowstorms, of which there have been so many this month, have been accompanied by all the indications of a true cyclone.

January 23.—Another small snowstorm, with very considerable barometrical depression, occurred to-day. There was the same paucity of upper clouds already so frequently mentioned, and the wind veered from the southwest to the northwest.

February 4.—At 9 p. m. it cleared and a slight aurora was perceptible.

March 1.—The sky very transparent. An aurora of considerable brilliancy appeared in the evening. Toward 10 p. m. streamers began to play, they had but little transverse motion. By 11 p. m. the aurora was waning.

April 10.—In the evening there was a very brilliant aurora. Commencing about 8 p. m., it attained its greatest brilliancy about 8.45 p. m. The streamers were very well marked, but without any great liveliness of motion. The horizontal motion was from east to west. Beneath the streamers the dark band was strongly marked, but of very irregular form, presenting a circular but jagged outline. At 8.45 p. m. a portion of the aurora separated itself from the rest. This separated portion formed a band two or three degrees in breadth and of a pale, mild light, which extended from the eastern horizon, passing a little to the south of the zenith, to the western horizon. Remaining apparently stationary, it gradually waned until, at 10 p. m., it was scarcely visible. The other and normal portion of the aurora lost brilliancy the moment of the separation.

May 9.—The wind blew from southwest and west till 7 p. m., when it suddenly changed to the north. The temperature simultaneously fell from 68° to 52°. At 8.30 p. m. a faint aurora became visible. It consisted of streamers with a horizontal motion from east to west. At 10 p. m. and onwards till midnight only a faint light was visible. The aurora occupied the whole northern sky up to about 60°. There was not the slightest appearance of the darkness usually found beneath the aurora. The light went right down to the horizon.

May 18.—At 10 p. m. a faint aurora was observed. A pale light, slightly tinged towards the north-northeast with red. Towards the north-northeast there was also an approach towards well defined streamers. The aurora there also attained its greatest height—about 40°. The dark shadow beneath was well defined.

May 24.—An aurora was observed at 8.45 p. m. It consisted at first of pale streamers of small brilliancy, reaching as far as the pole star, and having a horizontal motion from east to west. No shooting motion observed.

May 24.—An aurora was observed at 8.45 p. m. It consisted at first of pale streamers of small brilliancy, reaching as high as the pole star, and having a horizontal motion from east to west. No shooting motion observed.

June 10.—An aurora, consisting almost entirely of a diffused light, was observed at 8.30 p. m., and continued with little change until midnight, when observations ceased.

July 3.—At 11 p. m. a faint aurora was observed. It consisted of an auroral light, extending only a degree or two above the horizon, and streamers. The streamers, in patches of different intensity, extended from northeast to northwest and reached as high as the pole star. They were nearly stationary as regards horizontal motion.

July 7.—At 8 p. m., while yet the light of the sun lingered in the northwest horizon, a reddish light was observed in the northeast. As the light of the departing sun became fainter this showed itself to be an aurora, which occupied the whole northern horizon from the northwest to the northeast. The reddish light had meanwhile given way to a uniform pale light. The aurora consisted of a dark band of about 8° in height, a bright arch of dim light surmounting it and raising it to about 20°, an occasional streamer reaching down to the horizon and extending to about 25° in height.

July 8.—At 9 p. m. an aurora was observed. When first seen it consisted of streamers rising to nearly the height of the pole star, a circle of pale uniform light of considerable brightness, and the usual dark band beneath. Cirro-stratus in small quantity stood out in clear relief from the aurora.

July 10.—An aurora of small proportions at 10 p. m. was partially visible, the northern sky being partially obscured by clouds. As far as seen, it consisted entirely of streamers and reached to about 30° height.

August 3.—Aurora visible from 8.45 p. m. till about midnight. Most brilliant at 9.15, at which hour a narrow streamer of pale color extended from the horizon to the zenith. A dark segment was very plainly visible, extending from the west of north to the east point, and above the heavens were illuminated to the height of 25°.

August 8.—Faint auroral light at 8 p. m. beginning to make its appearance, dark segment along the northern horizon. At 9 p. m. aurora more bright and distinct; appears now as an arch of pale straw color, extending from west of north to north of east and about 15° in altitude; 9.30 p. m., aurora suddenly looms up very brilliantly, and extends from west of north nearly to the east, streamers extending to various heights, some reaching the zenith. The colors are very bright and varied, some of a green, others violet, and on the extreme eastern corner a diffused red; 10 p. m., a very singular and beautiful arch of light, of a white color, suddenly shoots up from about 20° above the southeast horizon, extending to about 70° above the western horizon and drifting with the south wind. This arch is so dense that it obscures the stars behind it. It continued about ten minutes and then gradually disappeared, commencing in the east. The illumination in the northern sky has now assumed a bluish shade, and above the dark segment (which is now black) resembles the folds of a curtain gently fanned by a light breeze. Pale violet streamers still extend nearly to the zenith; 10.30 p. m., sky partly obscured by cirro-cumulus clouds and aurora not so bright; midnight, clouds have cleared away and aurora is as bright as ever; 1.30 a. m., complete corona, streamers all joined at zenith; 6 a. m., the auroral display continued until daylight, and the number of shooting stars, especially between 2 and 3 a. m., are very unusual.

August 14.—Faint aurora first noticed at 10.10 p. m.; faint white or pale yellow beams (or streamers) shot up from the usual dark segment (about 30° above the horizon) nearly to the zenith and extending from a little west of north to the northeast. These streamers rapidly became more brilliant, and by 10 p. m. had extended from the northwest nearly to the east and shot up beyond the zenith. At 11.45 a complete corona was visible, and the sky exhibits a great variety of tints. About 25° above the horizon the aurora assumed the appearance of a brilliant curtain of frequently changing hues, some portions of the sky being white, others green, others straw color, and now and then (either in the northeast or northwest) a rosy hue deepens to a crimson, and at one time to a blood red. The beams were in constant motion, and waves of bright light traversed the sky continually, both from the east to west and from the horizon to the zenith.

September 4.—Faint aurora visible.

September 5.—A brilliant meteor was observed at 8 p. m. Its first appearance was a little north and east of the zenith, moving in a direct line, about 20° south of east. A line of bright white light showed its course, and remained several seconds after it had passed. When it had reached about a third of its distance it went out almost for a second or two then brightened up and moved on in the same line, then for a second time disappeared for several seconds. It was then renewed again brighter than ever, and still moved on in the same direction until it finally disappeared entirely. This white light was intensified now and then with a shade of red. The entire display lasted nearly half a minute.

August 7.—At 11.12 hail of very large size fell continually for about five minutes. As the storm set in the barometer rose rapidly and the thermometer fell from 78° to 67°, and was as low as 64° during the continuance of the hail.

September 24.—Barometer falling and southerly wind continues, and at noon is blowing a gale (50 miles per hour) accompanied by light rain.

October 13.—A few flakes of snow fell at different times during the day; the first of the season.

October 14.—A very brilliant auroral display, first noticed at 9.30 p. m.; it lasted till midnight and showed to the greatest advantage at about 10.20 p. m., when converging rays of a variety of hues, from a rose color to a vivid green and purple, extended nearly from east to west and almost to the horizon.

October 18.—Faint aurora, first noticed at 12.03 a. m., increased in brilliancy very rapidly and was at its maximum at 12.30 a. m., when an arch of white to purple-violet color extended from northeast to northwest, in the latter direction assuming a rosy hue; this arch was about 45° in height, and streamers in constant motion (of pale color) extended nearly to the zenith. At 1.15 a. m. aurora had disappeared.

1873.

January 23.—Barometer falling at 7 a. m., with sky covered with stratus clouds of a threatening aspect. At that hour a brisk wind was blowing from the northeast and at 7.30 a heavy snow, in small flakes, began falling. Thermometer stationary at 23°. The wind increased in velocity during the day, reaching a maximum velocity at 8 p. m. of 36 miles. The snow continued to fall in blinding drifts during the day and night, at times being so heavy as to fill the air completely and obstructing the vision at short distances.

The oldest inhabitant declared that he had never witnessed such a storm. Sufficient snow was collected in the gauge to measure .05 inch; the amount which fell was estimated at from 5 to 6 inches, or .50 to .70 inch melted. The persistency of this storm was something remarkable, extending, as it did, without cessation, over a period of 18 hours.

January 29.—Very low temperature early in the morning; the thermometer falling to 15° below zero.

February 4.—Beautiful display of zodiacal light from 6 to 7 p. m. The light was of a brilliant crimson, deepening in shade near the horizon, and generally fading into a pale yellow until lost in the sky. No line of demarkation could be traced, but the light was visible in the center of the arch to a height of from 15° to 20°.

March 26.—The storm continued with scarcely unabated severity until daylight, the wind reaching a velocity of 38 miles per hour at 1.30 a. m. Snow fell until 8.30 a. m., and the wind began to decrease in velocity. At this hour the depth of the snow, in drifts on the streets, was from 2 to 6 feet.

April 6.—Rain began to fall at 6.30 p. m., and a thunderstorm of considerable violence from that hour until 10.30 p. m. The flashes of lightning were very vivid, and mostly of the variety known as sheet lightning. Occasionally a flash of zigzag lightning was seen, with an accompanying peal of thunder. This is the first marked thunderstorm of the season and occurs in conjunction with a very high temperature (83°) and a brisk south-southwest wind.

May 1.—Thunderstorm during the evening, accompanied by heavy rains and brisk northeast winds. The largest amount of rainfall during any eight hours of the year up to this date was from 4 p. m. to midnight. Very heavy peals of thunder and vivid flashes of lightning characterized the storm.

June 18.—At 9 p. m. the first indication of an aurora made its appearance in the northern heavens, continuing to increase in size and appearance until 11 p. m., at which time it attained its maximum proportions. The display rose from a dark segment extending 15° each side of the magnetic meridian, and first consisted of a poorly defined whitish hue, but gradually increased in brilliancy until it assumed the pale red color peculiar to such displays, while well defined beams of great brilliancy commenced shooting upward from the western side, attaining an altitude of 45°, and gradually passing over the segment to the eastern extremity.

September 5.—The account of yesterday's blow given by this morning's papers makes it of far more serious nature than could be anticipated by parties in the city. All the captains of vessels that came into port last night speak of it as a hurricane, lasting about an hour, and doing great injury to all the vessels that encountered it. A peculiar feature of the storm is that, while the papers all speak of it as being from the south over the lake, it was from the west over the city, another where one of the vessels encountered the sea running from the southeast, while the wind was from the southwest.

September 15.—After midnight the wind, which had been blowing from the south, shifted to southeast, and commenced to blow a gale, increasing in strength until about 8 a. m., when it commenced to moderate, and then decreased gradually until 5 p. m. During its continuance over the city a number of roofs were torn from buildings and walls of others being erected torn down; the damage in several sections amounting to thousands of dollars. The wrecking of the Ironsides, a steamer plying between Milwaukee and Grand Haven, by that blow caused the loss of a number of lives and one of the finest vessels on the lake.

September 19.—The first frost of the season occurred during the past night.

September 30.—A review of the past month reveals the fact of its having been the most disastrous one on shipping that has occurred for some years past, especially for the season, while its varying changes have been such as to cause unusual comment by the press, seafaring men, and the community at large.

December 4.—Barometer fell .51 inch between midnight and 7 a. m. this morning, but the wind constantly increased, until at 6.35 a. m. it was blowing 38 miles per hour. Great damage was done by the storm in this city. Several buildings were unroofed, and some in process of construction blown down. Trains were all delayed, and several vessels tied to the docks were blown from their moorings.

1874.

March 3.—The first thunderstorm of the season, accompanied with brilliant lightning, broke over the city between 7 and 8 this a. m.

June 6.—A storm struck the city and was the most violent, and, in some respects, the most remarkable that has visited this city for some years, as regards the heavy rainfall, the display of lightning, and the total absence of wind. The storm, which came from the west, moved slowly. It began raining about 8½ miles south of this office at 7 p. m., and rained in torrents for nearly two hours, during which time, although the sky was clouded and sheet lightning incessant, no rain fell in the central part of the city.

August 21.—5.15 p. m. wind suddenly shifted to north and was followed by one of the heaviest rainfalls witnessed in this city for some years; 2 inches falling from 5.30 to 8 p. m., during which time the temperature decreased 19°.

October 3.—At 9 p. m. an auroral light first made its appearance in the northern heavens. It first assumed a bright whitish color, retaining it until 11.30 p. m., when the color changed to a reddish cast, and bright flames shot forth from the luminous mass, extending to an altitude of 45°; this continued until midnight, up to this time the azimuth of the display did not exceed 30°.

October 4.—The auroral display ceased at 3 a. m., having after midnight attained an altitude of 75° and an azimuth of 45°.

November 2.—The change in temperature from 31°, during early morning, to 65°, during middle of day, is the greatest daily change that has come under the notice of the observer since the establishment of this station.

1875.

January 8.—The temperature decreased from 31° at 4 p. m. to 15° below zero, a change of 46° in 8 hours. A change said to be unprecedented in this section in years past.

January 9.—During the night the thermometer showed the temperature to be 20° below zero, while thermometers in various parts of the city ranged as low as 30° below, according to locality and exposure. It is said to be the coldest night experienced in this city for years past.

January 24.—Between the hours of 9 and 10 p. m. the rising moon presented a very peculiar appearance, seeing it as it was rising from the lake. From some cause in the atmosphere its rays seemed entirely concentrated into a vertical belt of the same width as the moon, and extending above and below about 5°.

This peculiar concentration of the rays was probably due to the amount of moisture in the air over the lake, for the concentrated rays gradually expanded into proper form as the moon continued to rise.

February 1.—Two bright, luminous spots, one on either side of the sun, were visible for a short time this morning at early sunrise. These are what are termed "sun dogs."

February 3.—The wind from 2 to 4 p. m. was blowing at the rate of 40 miles per hour. From 4 p. m. it abated, but still continued high until after midnight. So high a wind has not been experienced in this locality since the night of the great fire that destroyed the best portions of the city. Considerable damage was done to buildings throughout the city, and several vessels were torn from their moorings and badly damaged before being secured.

February 12.—Temperature 13° below zero this morning, and on the outskirts of the city as low as 20° below. The continued cold weather of the past six weeks has frozen the ground to the depth of from 4 to 6 feet, in some places freezing the main water pipes. A large number of service pipes have been frozen for some days, and great inconvenience is the result.

March 14.—At 8.55 p. m., and until 9 p. m., hailing, some of the hail being unusually large; one inch in diameter being the medium size.

March 16.—Gale continued until midnight. Considerable damage was done to buildings in course of erection, and to lighter objects exposed to its violence, but none to the shipping interests.

June 21.—The rainfall from 2.30 to 3.30 p. m. was unusually heavy, amounting to 1.55 inch.

June 23.—Between 2 and 3 a. m. a very heavy squall passed over the city from the southwest, doing considerable damage to buildings in course of erection, also injuring some vessels exposed to its fury. It was accompanied by rain, heavy thunder, and lightning.

July 15.—A very sudden and severe squall passed over the city between midnight and 2 a. m. The squall passed from northeast to southwest, and was accompanied by severe thunder and vivid lightning, but no rain. Yesterday afternoon Professor Donaldson and a Mr. Grimwood, reporter for the Evening Journal, ascended in a balloon from Barnum's circus, and were blown out over the lake by the southwest wind. Fears are entertained that they are caught in the squall and probably lost.

August 5.—At 9 p. m. a very heavy squall struck the city, blowing for about five minutes at the rate of 45 miles per hour. A small quantity of rain fell at the same time. The heaviest of the storm passed to the southwest of the city, doing a great deal of damage to everything exposed to it, especially the crops.

August 7.—This morning's papers give a very distressing account of the damage done by the rain and storm of the 5th and 6th, and the loss to the farming community by the floods, the latter still continue; also accounts of several vessels being wrecked, but not in this vicinity.

September 9.—A very heavy rain commenced falling at 12.10 a. m., continuing until 8.30 a. m., commencing again at 3.40 p. m. and continuing until midnight; the total fall of the day being 3.50 inches, it being the heaviest fall for one day that has occurred in this city for months. At 6 p. m. the wind suddenly shifted from south to north, increasing in velocity until midnight, when it was blowing at the rate of 35 miles per hour. The fall of rain during the morning was accompanied by a brilliant display of lightning and heavy thunder. A fall of 24° from 2 p. m. to midnight.

September 11.—The worst fears of the disastrous effect of the storm of the 9th and 10th have been fully confirmed, and this morning's papers give a distressing account of the damage done, full particulars of which have been forwarded to O. C. S. O. by letter this day. Those exposed to the storm on the lake speak of it as the worst they ever encountered.

December 31.—The maximum temperature during the day was 68°, the highest that has been experienced for years. The same can be said for the whole month, the warmth of it being commented upon both by the public and the press.

1876.

January 31.—The past month has been remarkable for its warmth, the mean temperature being 15.5° higher than for January, 1875.

February 8.—Heavy thunderstorm commenced at 9 p. m., continuing until after midnight; bright lightning.

March 16.—At 12 noon the barometer had reached the lowest point in past two years, 28.965 inches (corrected), the fall in 24 hours being 1.101 inch.

April 28.—Warm and clear. Several steamers succeeded in forcing their way through the ice in the Straits of Macinac. This event is practically the opening of navigation.

May 6.—At 9.10 p. m. the city was visited by a violent tornado, which, though lasting but from two to three minutes, did damage in and about the city estimated at $250,000. The course of the tornado was from southwest to northeast, having a swift rotary motion from right to left, bounding along like a ball in its full force, apparently reaching the ground but two or three times. The last seen of it was on the lake in the vicinity of the "crib," at which place it demolished the fog bell and tower. It was also reported that numerous water spouts were seen in that vicinity at the time. During its passage the rain fell in torrents, and it was accompanied by thunder and sharp flashes of lightning. Many of the vessels in the lake were damaged to some extent.

September 26.—Aurora in the evening at 10 and ending at 3 a. m.; bright flashes of light from east to west, gradually fading out and then reappearing.

September 27.—A light frost was observed upon the walks this morning, the first seen in the city this season.

October 14.—The first snowflakes of the season fell to-day, but not in a sufficient quantity for measurement. The man at the "crib" telegraphed to this city at 9 a. m. that the wind at that place was blowing at the rate of 65 miles per hour and the waves were running 12 feet high. The wind at this station did not register over 24 miles per hour.

December 1.—The weather on the lake is reported as being very rough, and vessels arriving were thickly coated with ice. No vessels cleared during the day, and those that left yesterday were obliged to return for shelter. Vessels after arriving and unloading generally strip and tie up for the winter, and navigation has now practically closed at this port for the winter.

1877.

January 31.—The snow, which has been on the ground since November 30, has given 62 days of uninterrupted sleighing in the city, and is now fast disappearing.

March 20.—Heavy snowstorm commenced at 1.30 p. m., and at the same time several loud peals of thunder were heard.

April 2.—The southwestern portion of the city is badly flooded by water, caused by the overflow of the Desplaines River and canal. The low prairie is covered with water to the depth of several feet in some places, and considerable damage has already been done to streets and sidewalks.

April 3.—The flood in the southwestern portion of the city continued to increase during the night, and several large manufactories have been stopped by the water. The Chicago River is very high, and is discharging a rapid current into the lake, and many of the low docks and slips along the river are under water. The ice on the outer harbor and lake has disappeared, having been driven up the lake by the south wind. The muddy and impure water flowing from the river can be traced out into the lake for a distance of several miles and extends beyond the "crib."

June 20.—The propeller "Concord" succeeded in breaking her way through the ice in the Straits of Macinac at 2 p. m. to-day.

May 28.—A bright aurora during the evening was first observed at 8.15 p. m., brightest from 8.30 to 8.45, gradually growing fainter, and disappearing as the moon arose at 10 p. m. The arch had an altitude of about 25°, and from this bright streamers shot up to the zenith, and at times extended from 5° to 10° beyond that point. At times large bodies of light, of irregular cloud-like form, would appear in the east and disappear in the northwest.

May 25.—A violent storm of wind and rain passed over the station to-day.

July 2.—Heavy rain early in a. m., and at 5.45 p. m. a severe thunderstorm passed over the station, during which a few hailstones of a very large size fell.

October 11.—An aurora during the evening was first observed at 10 p. m. and lasted until 1 a. m. of the 12th. The brightest display being at 12.30 a. m. of the 12th. The altitude of the crown of arch was about 20°.

November 5.—The rain of last night turned to sleet and snow at 3.20 a. m., with a furious northeast gale. The schooner "Ohio" came ashore on the breakwater and was dashed to pieces. The "Gardner," "Coral," "Pennington," and "Chapen" were also beached in this vicinity, together with numerous other minor disasters.

November 9.—The schooner "D. G. Williams" struck the breakwater about midnight last night and went to pieces.

1878.

February 27.—Ice along the shore went out to-day.

March 6.—Heavy hailstorm reported at 2 p. m. in the suburbs 10 miles south of here. The storm is said to have lasted 20 minutes, during which time 1½ inch fell. The track was about 300 yards wide, and the hailstones were of an average size and uniformly globular.

March 17.—A squall lasting 15 minutes (10.30 to 10.45 a. m.) passed over the station, the wind attaining a velocity of 27 miles. No casualities reported.

March 24.—No vessels left this port while the signals were displayed, except the fore and aft schooner "Minnie Corbett," of Grand Haven, Mich. This vessel left port at 5 p. m. and attempted to weather the breakwater, but was compelled by the force of the gale and the heavy sea running to let go her anchors in the outer bay. During the night the gale continued to increase, sweeping the boat from her moorings and driving her bow on the breakwater, where she now lies breaking up piecemeal—a total wreck.

March 25.—The report of the keeper of the Life-saving Station at this port contains the following clause referring to the wreck of the "Minnie Corbett": "Her wreck may be attributed to the high wind and heavy sea from northwest to northeast, which caused her to drag her anchors; also to the want of caution in her commander in sailing from this port while the storm signals of the U. S. Signal Service were displayed."

May 24.—Down signals received at 9.50 a. m. Not justified, although in the immediate suburbs the wind blew a fierce gale, uprooting trees, unroofing several houses, and otherwise injuring much valuable property.

July 6.—A large and brilliant meteor was observed at 3.05 a. m. Was first seen within the constellation Ursa Minor, its direction being through the Corona, disappearing at the horizon a little south of Libra. This meteor was as large as the full moon, and while visible (about 12 seconds) gave a light of three times the intensity of the moon on a clear night. The "cloud" in the wake of this phenomenon was a pale luminous streak, covering the entire track of the meteor. It had no apparent motion, but disappeared gradually from west to east, and was entirely obliterated in 11 seconds.

July 26.—The rain of last night continued until 5.55 this morning, and is the heaviest shown by the records of this station. The greater quantity of rain (I should estimate two-thirds of the whole) fell between 11.30 p. m. of the 25th and 2.30 a. m. of 26th. The damage caused by rain would be a difficult matter to estimate, being so general throughout the entire city and suburbs. Railroads and culverts were washed out, cellars flooded, buildings in course of erection leveled, sewers choked (although their guaranteed capacity is for one inch rainfall per hour) and the streets and sidewalks more or less damaged. The total fall was 4.14 inches.

August 8.—A squall struck here at 2 p. m. which, though not attaining a velocity of more than 22 miles an hour at this station, must have reached at least twice that force on the lake within 10 miles of here. Every vessel within that radius lost some of her canvas; two yachts lost all their spars and rigging; a steamer and two schooners were driven aground on the northeast breakwater; one fishing smack was capsized, and several minor casualties are reported. The wind during this squall was from the southwest, but after the squall had passed the wind veered suddenly to the north, remaining there for 15 minutes, and again backing to the southwest. The temperature, meanwhile, dropped from 91° to 80° between 1.50 and 2 p. m. The barometer was remarkably steady, giving no premonition of this disturbance.

August 12.—Meteoric showers from 10.15 until midnight, from every quarter of the horizon. The number of meteors that fell (even for a fraction of a second) could not be computed. The display is considered one of the most remarkable ever observed here.

September 21.—Light hoar frost, the first this season, last night.

September 25.—Up signals received at 11 a. m. The heaviest rainstorm ever seen in this city swept over at 11.30 a. m., lasting 8 minutes. It was accompanied by sharp thunder and diffuse lightning, which illuminated the sheet of water that was coming down in a manner similar to an electric discharge on a plate of wet glass. The direction of the wind just before the storm was southerly, and a drizzling rain had been falling for some time. The wind backed suddenly to the west-southwest, and in less than thirty seconds the deluge came on. The streets in two minutes looked like so many canals; cellars were flooded in five minutes, and the houses on the opposite side of the street could not be distinguished, even in outline, through the semi-opaque mass.

A sprinkling of hail fell when the rain began to slack up, the stones averaging ¼ of an inch in diameter, irregular in shape, and with a formation of hard, transparent ice. The rain gauge at 11.40 a. m. showed a fall of .97 inch, .92 inch of which, I have estimated, fell in 8 minutes, being at the rate of nearly 7 inches an hour, or more than three times the guaranteed capacity of the city sewerage. The barometer had been falling rapidly and steadily for 16 hours, and fluctuated very slightly during the storm.

November 2.—Signals hoisted yesterday, justified, wind 26 miles. All vessels remained in port during the display; those caught out on the lake were roughly handled. Captain Saunders, of the bark "Kelderhouse," was lost overboard during gale. The bark "Woodruff" wrecked, and two of her crew missing. The schooners "American," "Australian," "Montpelier," and one unknown, were washed ashore, and the bark "Rutter" sunk, besides numerous minor disasters.

December 31.—The depth of snow on the ground at this date is about 14 inches.

1879.

January 31.—About 8 inches of snow on the ground at this date.

February 28.—About 25 inches of snow on the ground up to date.

April 1.—Navigation opened.

April 2.—Hard frosts at night.

April 10.—Geese flying north.

May 25.—Heavy rain and thunder storm commenced at 1 a. m. and ended at 6.30 a. m. There was no perceptible interval between the lightning flash and the thunder crash, and the fluid ran along every telegraph line in the city, destroying hundreds of instruments and other telegraph material, and ringing a general fire alarm at fire department headquarters. Fortunately no lives were lost, nor other property seriously damaged, owing probably to the great conducting power of the deluge of rain that fell during the fiercest interval. Several hundred cellars were flooded by the rain in the southern and western districts.

November 20.—A heavy gale pervaded the lake during the afternoon of the 19th and morning of the 20th, causing great damage to vessels. The schooner "Clara Parker" driven ashore at the foot of 30th street.

December 16.—Close of navigation for sailing fleet and steamboats.

1880.

February 29.—About 4 p. m. a peal of thunder and a flash of lightning accompanied by a small amount of rain.

March 10.—Hard frost during night. Wild geese observed flying in a northerly direction.

April 19.—Heavy wind storm at 2 a. m. Blew at the rate of 35 miles per hour for the first 15 minutes, lulled afterwards until 5 a. m., when it began again. Heavy peals of thunder and vivid flashes of lightning (zigzag) early in the morning, and at intervals up to dawn. Rain in heavy dashes, of short duration, at intervals up to about 7.25 a. m. Windstorm ended at 5 p. m. Maximum velocity 35 miles from the south. Much local damage reported.

Tabernacle and Plymouth churches were damaged by wind, the former having a chimney carried off, windows broken, etc., and the latter a part of the roof. No damage to shipping yet heard from.

May 25.—At 12.53 p. m. a sharp, sudden report was heard from the southeast, resembling considerably the report of a cannon, and Private Conrad reports that just at that time he saw, for an instant, a *ball of lightning.*

June 6.—Heavy thunderstorm early this morning, with brilliant sheet and zigzag lightning. Heavy windstorm from the southwest at 5.30 a. m., lasting until 4.30 p. m. No known damage in this vicinity. Much damage reported farther up the lake, maximum 36 miles.

August 12.—Clear weather. Aurora observed at 9 p. m., consisting of a dark segment on the northern horizon, clearly defined but slightly irregular in outline. At 9.05 p. m. segment disappeared and was immediately followed by a display of faint streamers shooting up towards the zenith, highest from a point due north, and extending 45° and 50° east and west of it. At times these streamers reached a height of about 75°.

August 13.—Aurora again observed at 8.25 p. m., which consisted of pale, phosphoresent, faintly-defined vertical shafts, extending upwards to about 30°, from a faint haze bank in the northern horizon, and from about 165° to 195° of azimuth. At times a feeble lateral movement from east to west was observed.

August 14.—Aurora recurred faintly at 12.18 a. m. Faintly defined shafts shot up about 30°. Faded at 12.20 a. m. Heat lightning in the northeast at 12.18 a. m.

September 29.—Light frost this morning. First observed at station this season.

October 1.—Heavy thunderstorm at 3.30 a. m., with brilliant zigzag lightning and frequent heavy rain showers up to about 6.30 a. m. Hail size of buckshot.

October 17.—Wind continued with but slight abatement up to 2.15 a. m. One unknown schooner reported sunk out in lake a short distance from port. Owing to timely warning given by signal, this is the only serious disaster yet reported to shipping in this vicinity. In South Chicago, "North Chicago Rolling Mills," partially built—walls 14 inches thick—were blown down, burying several workmen in the ruins. Part of Wheeler's new elevator, in course of erection, was blown down, also about one-half of Illinois Central elevator.

October 18.—The unknown schooner referred to yesterday found to be the "David A. Wells," which is reported to have gone down with her crew of 8 men.

October 19.—The steam barge "Trader," running between Chicago and Muskegon, was found waterlogged, with parts of works swept off. The crew were saved. The steamer "Alpena," which left Grand Haven on the night of the 15th, with about 60 persons on board, including her crew, is also believed to have gone down. She was seen by other vessels about 30 miles from Chicago. Fragments of wreck were picked up on eastern shore south of Grand Haven, marked "Alpena." The height of the waves and the fury of the storm is the subject of general comment even among old mariners.

1881.

February 27.—Heavy hail for a few minutes shortly after noon. Stones as large as ordinary peas.

March 19.—Windstorm from 4 a. m. to 11.15 a. m. Maximum velocity, 35 miles from the northeast at 7.35 a. m. Prevalent direction during storm, north. No known damage.

April 11.—Propeller "Oconto" arrived to-day from Milwaukee. First arrival of steamer. Navigation practically opened.

April 21.—Flood in Chicago River caused by overflow of Desplaines; southwestern portion of city inundated; considerable damage done to property.

June 29.—Heavy thunderstorm from 2 to 4 a. m., accompanied by heavy rain from 2.57 to 4.20, and heavy windstorm from the southwest at 2.55, lasting for 18 minutes. Maximum velocity, 32 miles.

July 20.—Heavy thunderstorm at 10.30 a. m., lasting about 1¾ hour, accompanied by heavy rain and brilliant zigzag lightning.

July 21.—Heavy thunderstorm early this morning, with unusually intense electric display.

August 3.—Highest temperature this year, 93.8°; a few cases of sunstroke.

August 4.—Highest temperature since 1874, maximum 97.9°.

September 13.—Aurora visible at 1.10 a. m., consisted of a faint arch of light of about 5° altitude, extending from about 8° west of the north point to 12° east.

November 11.—Rain from about 5.15 a. m., heavy in general up to about 8 p. m., when it changed to light; 3.18 inches up to 10.18 p. m.; inundated low-lying portions of the city.

1882.

April 9.—Heavy thunderstorm early this morning, with very heavy rain at 1.30 a. m.

April 10.—Windstorm continued up to 2.15 a. m. Schooner "Espanola," laden with ties, en route from Grand Haven to South Chicago, was wrecked off the harbor early this morning.

April 16.—Aurora observed at 9.40 p. m. Consisted of a hazy segment about 15° high, surmounted by an arch of light about 5° broad, extending from about 40° east of north to 30° west. The arch slowly ascended, and at 10.15 was about 40° in altitude. During the next 10 minutes it widened towards both horizon and zenith and disappeared, leaving only a faint glow. About 10.30 vertical columns began to shoot up from near the north point towards the zenith, and were soon accompanied by similar displays in the west first, and afterwards in the east; the aurora, meanwhile, having extended laterally to about 55° west of north, and to about 70° east. The shafts gradually extended laterally, and finally converged to a point about 15° south of the zenith, changing in color from pale yellow to blue, red, and crimson.

About 15 minutes to 11 it attained its greatest brilliancy. The point of convergence near the zenith, a circular black nucleus presenting a decided contrast to the brilliancy of the converging beams which varied from a deep red at their summits to a pale blue near the horizon. At this time the display covered about two-thirds of the sky. At irregular intervals, a tremulous swinging movement was observed from east to west, and *vice versa*. About 10.55 it began to fade, and at 11.00 a faint glow remained, varied by occasional feeble beams shooting up towards the zenith from the horizon.

The wires of the various telegraph offices were unusually affected. At the Western Union office the batteries were detached and wires worked both to Omaha and New York, the current being very powerful. Wires running north and south were also much affected, but not nearly so powerful as those running east and west. Said to have been the most intense electric storm ever experienced in Chicago.

April 17.—Aurora continued up to dawn, was characterized by recurring fits, consisting chiefly of vertical shafts shooting up from the horizon with great rapidity and quickly disappearing, and a faint luminous glow resembling dawn.

June 27.—Heavy thunderstorm beginning at 4.40 p. m. and lasting for about an hour.

August 4.—Faint aurora at 9 p. m., extending from about 10° east of north to 35° west.

October 5. —Aurora at 9.15 p. m. A faint luminous glow on the northern horizon, extending from about 15° west of north to about 25° east of north, and in altitude about 25° at its center. At about 10.30 streamers, faintly defined, shot up from the north to about 35° in height, and slowly faded away. Soon afterward an auroral arch formed, extending from northwest to southeast, apparently about the breadth of an ordinary rainbow, but wider at its extremities.

November 13.—First heavy frost of the season this morning. Light flurries of snow from 2 to 7.40 this morning. First snow of the season.

November 17.—Rain at 4 a. m. Remarkable intensity of atmospheric electricity reported by various telegraph companies in the city. Evidences of aurora at intervals during the evening, seen faintly through occasional rifts in clouds. It consisted of a pale light and was soon obscured.

November 18.—Auroral evidences again observed early in the morning, consisting of a bright light at intervals through spaces between the clouds.

November 20.—Diffuse auroral lights visible from behind cumulo-stratus clouds between 2 and 5.10 p. m.., extending in altitude to about 30° and in azimuth from about 150° to 240°. No special characteristics visible, merely a luminous glow at the summit, with the base obscured by clouds.

1883.

January 22.—Clear, with intense cold; animals freezing at stock yards and suburban towns. Minimum 17.2° below zero; maximum 3.8° below. Coldest weather recorded since January, 1879.

April 28.—Storms very severe on Lake Michigan. Several vessels left port after signals were hoisted, and were obliged to put back. Others arrived with loss of spars and canvas. Schooner "S. Bates" went ashore at Winnetka (12 miles distant) and went to pieces. Crew saved by Life-saving Service. Heavy sea undermined walls of Farragut Boat Club building, causing it to fall.

May 3.—Thunderstorm, accompanied by hail, from 6.40 to 8.46 p. m.

May 9.—Heavy thunderstorm began at 6.50 p. m., with severe squall.

July 29.—Aurora of a pale light color observed at 10 p. m. Altitude of arch about 15°; no noticeable streamers, though edge was somewhat ragged. Above aurora, and separated from it, were spots of light similar to what might be produced by light shining upon fleecy clouds. Aurora continued until about 11.15 p. m.

August 27.—A sudden change in pressure at 10.20 p. m. reported by superintendent of gas company. Nearly all the gas lights went out. Three water gauges in parts of city, at distances of 1½ miles from each other, read 3 inches, 1½ inch, and 1 inch. No unusual change in office barometer,

October 18.—Life-saving crew say a heavier sea ran into the harbor than they ever before experienced. A number of tug boats in lighthouse slip compelled to seek safer quarters. Scow "Petrel," at Sheboygan, the only loss reported, but several vessels sustained damages.

October 31.—A large fleet are stormbound. Master of schooner "Robert Howlett" reports the roughest usage he ever experienced on the lake. The schooner "Mary Naw" is reported a total wreck near Grand Haven.

November 11.—Temperature fell rapidly in the afternoon; wind increased in violence from west to northwest, blowing 26 miles an hour. Captain McKee, of Lake Crib, reported a velocity of 60 miles an hour. Several vessels lost deck loads; schooner "Unadilla" lost head-gear and jib, and foresail split. "Genet Smith," "Amelia Mosher," and many other vessels sustained losses of rigging. The storm is universally conceded to be the most violent that has swept over Lake Michigan this year.

November 12.—Many vessels arrived ice covered. The schooner "Helen Pratt" was covered with ice to the depth of several inches, and her staysail and jibs were frozen so that they could not be lowered during the day. The barges "Transfer," "C. O. D.," and "Wolverine" arrived from Grand Haven badly demoralized. There is much anxiety for safety of schooner "Arab" and tug "Protection," supposed to have gone down with all hands, between here and Milwaukee.

December 4.—Wild geese flying southward this morning.

December 9.—Sunset of unusual brilliancy.

December 11.—Sky brilliantly illuminated preceding sunrise and at sunset.

December 15.—Chicago River frozen over.

December 17.—Wild geese reported as flying southward.

December 26.—Snowbirds seen.

December 28.—Navigation virtually closed on 15th instant. The season just closed has been an eventful one; disasters being as large as any previous, with exception of 1866 and 1872, when lives lost in the former amounted to 445, and in the latter to 120.

The number of casualties of a prominent nature during 1883 were 918; losses on hull and cargo foot up to $2,825,848; on logs and timber rafts, $15,000; of this loss, $991,915 occurred on Lake Michigan; disasters, 522. The most important loss was the steamship "Oakley" (H. C.), which, with her captain (E. Streck) and 4 of her crew went down in the gale of November 14th. Loss of property $100,000.

The sunset this evening and (when visible) each evening since the 9th was extremely brilliant, attracting much attention.

1884.

January 2.—Gulls observed hovering overhead, apparently confused.

January 29.—Falling barometer and warmer weather Gulls flying inland.

February 19.—Cold wave signals at 9.30 a. m.; temperature at time, 50.5°. The number of persons visiting office for information of cold wave testify to the importance of this signal and the notice taken of it by the public.

March 14.—Larks and robins seen in the suburbs. Ice 19 inches in thickness in the Desplaines River, now being cut.

March 24.—Navigation resumed on Lake Michigan.

June 22. —Heavy thunderstorm from 2.30 to 4.55 p. m.

July 24.—A heavy thunderstorm from 4 to 8.45 a. m., accompanied by a brisk wind.

December 18.—Coldest day of the month. Temperature remained below zero all day, mean —6.6°.

1885.

February 10.—No mails received to-day. The temperature remained about 10° below zero all day, going down in the evening.

February 11.—Minimum temperature, —13.7°; the lowest for any February since establishment of station.

May 24.—A thunderstorm occurred from 8.30 to 8.50 p. m. The storm approached the station from the southwest and went towards the north. The temperature, which was 69° before the storm, rapidly rose to 80° after it had passed. The wind was from the east before the storm, shifted to southwest afterwards.

June 2.—A thunderstorm in evening, beginning at 6.12 p. m. and ending at 6.53 p. m. The temperature just before the storm was 75°, wind southeast. As the storm approached the temperature rose rapidly, marking 80° as the storm broke over the city. The wind veered rapidly from southeast, southwest, and west, remaining between south and west during the storm, but backing to the southeast as the storm passed to the east; the temperature rapidly falling to 70.9° at the same time. Sharp lightning and heavy thunder accompanied the storm.

June 3.—A thunderstorm ended at 2.15 a. m. There was no thunder heard or lightning observed after midnight. The rain gauge overflowed, and the 7 a. m. measurement was made from the snow gauge, showing a fall of 2.90.

June 7.—About 8 p. m. the sky, which was clear a moment before, became rapidly covered with clouds, and the temperature fell from 86° to 62° in 20 minutes, at the same time the wind increased to brisk and veered from the southwest to north.

June 21.—Light rain at intervals from 7.30 a. m. to 12.45 p. m. A thunderstorm prevailed during the latter part of this rain. It came from the southwest and moved towards the southeast.

July 4.—Hail began falling at 2.05 p. m., hailstones were round and about ⅛ inch in diameter.

July 7.—A sharp thunderstorm from 5.50 to 6.20 p. m. It came from the southwest and went northeast. A slight hailfall from 6.05 to 6.06 p. m.; stones about ¼ inch in diameter.

July 9.—Thunder was heard between 12.15 and 4 a. m. This storm came from the northwest and went towards the southeast. Temperature 81°, wind southwest before, and 71°, southwest after the storm.

July 14.—Thunderstorm from 8.40 to 9.30 p. m., with heavy rain. It moved from west to east. Temperature 80°, wind southwest before, and 75° and west after the storm. The lightning was very vivid.

July 19.—A thunder shower passed north of the city from west to east. A single clap of thunder was heard at 11.20 a. m. At 11 a. m. the wind was southwest, temperature 85.6°; at 11.40 a. m. (sky overcast and threatening) wind east, temperature 66.7°.

July 23.—A thunderstorm came from the west and went eastward.

August 2.—Decidedly low barometer. Lower temperature. Fresh easterly wind, increasing to brisk by noon, and blowing a gale during the afternoon and evening. Rain began at 12.50 a. m. and continued without intermission (generally heavy) all day. In the first 8 hours .14 inch fell, in the next 8 hours 1.64 inch fell, and the last 8 hours 3.85 inches fell, making the total for the day 5.63 inches. Sewers were filled.

August 21.—Thunderstorm. At 3.50 a. m. thunder southwest.

August 23.—Thunderstorm during early a. m. Light rain began at 8.15 a. m.

September 15.—Though not noticed at the station, it was learned that a bright aurora was seen by persons in the country adjacent. It began at 9 p. m. and ended about midnight. There were some streamers and merry dancers.

October 4.—Killing frosts reported from the adjacent counties.

October 8.—The sun rose very red at 7.06 in a clear sky. Fresh northwest wind, fair and clear weather. The sun set in cumulo-stratus clouds which were brilliantly colored with red.

October 29.—Incoming vessels report a severe gale on Lake Michigan. Nothing going out of this port. The severest storm of the season.

November 4.—Thunderstorm moving from southwest to northeast. First thunder 6.20 a. m.; loudest, 7.15 a. m.; last heard, 7.20 a. m.

December 9.—During the early morning there was some lightning. A single clap of thunder heard at 7 a. m.

1886.

January 13.—River and harbor frozen. Harbor covered with ice of considerable thickness. Ice on Chicago River is about 6 inches thick.

March 4.—Bishop's ring visible in afternoon; it was 15° in diameter and gray colored, slightly partaking of pink.

March 11.—A flock of wild geese was seen flying northward during the morning.

March 18.—Bluebirds and robins were to-day observed in the vicinity of the station.

March 20.—Captain Rogers, of the propeller R. B. Taylor, which arrived to-day, says that navigation is open so far as the upper part of the lake is concerned. Thunderstorm began at 5.25 and ended at 5.40 p. m. Immediately after the loudest report unusually large drops of rain began to fall, but soon resumed their normal size.

March 26.—Bishop's ring of a faint purple hue and of about 15° radius was observed in the afternoon.

April 2.—Bishop's ring visible in morning and afternoon, of a grayish pink color, 15° radius. Northwest wind with cloudy weather; clear in the evening.

April 16.—Navigation now opened. A large fleet of vsssels left port for the straits to-day.

April 21.—Vessels are reported to have forced a passage through the ice in the Straits of Macinac to-day, and navigation between the upper and the lower lakes may therefore be regarded as now open for the season, being a fortnight earlier than last year.

April 25.—Several vivid flashes of lightning and heavy thunder about 3.40 a. m.

May 4.—Thunderstorm began at 12.45 p. m. and ended at 3.25 p. m.

May 9.—First thunder heard in the northwest at 11.55 p. m. Wind east, temperature 56.2°. Loudest thunder from 12.35 to 1 a. m., and again at 3 a. m.; last thunder at 3.45 a. m. Hail fell from 7.30 to 8 p. m. The stones were not large nor numerous; now and then, however, a large jagged piece of ice was noticed. During the hail the loudest thunder was heard.

May 12.—At 5.15 p. m. a heavy thunderstorm was seen approaching from the southwest. Hail began at 5.43 p. m. The stones were composed of pieces of ice coated with snow, varying in size, some being as large as a hickory nut, while others were smaller. Hail ended at 5.46 p. m., with heavy rain.

May 17.—A mirage was reported as seen over Lake Michigan at 4 p. m.

June 5.—Rain began at 2.45 p. m., ended at 3.20 p. m. Hail began at 3.05 p. m. and ended 3.07 p. m.

June 8.—Heavy frost was reported about five miles northwest of the city. Potato vines and vegetation killed.

July 9.—First thunder was heard 12.40 p. m. The storm moved from west to east.

July 13.—First thunder 4.30 p. m.; last, 5.20 p. m. Hail from 4.45 to 4.55 p. m. The stones were large and irregular, some being as large as walnuts. Several were noticed of irregular oval shape, with the long diameter of about 2 inches and the short diameter about 1½ inch, and having sharp, jagged points projecting from all sides. Most of the stones were formed of solid ice, and some were noticed which did not melt for an hour after they had fallen.

August 28.—At 8.30 p. m. lightning was seen in the western clouds, and at 9 p. m. the first (and very heavy) clap of thunder was heard. Loudest thunder heard at 9.42 p. m.; last, 10.45 p. m.

August 29.—Thunderstorm.

August 31.—At 10.01 p. m. a shock of earthquake was observed while reading the barometer. The wave movement appeared to be from nearly west to nearly east. The building rocked perceptibly, and map frames hanging against the walls were moved onward and backward, making a perceptible noise. The barometric column oscillated noticeably. The duration of the wave movement was about 7 seconds, and there appeared to be about two or three waves to the second. The barometric column stood .012 of an inch higher 8 minutes succeeding the shock than just before. Owing to the height of the building, the office being on the top floor, the wave movement was opposite to what it appeared.

October 1.—Killing frost and ice was observed this morning at 5 a. m.

November 8.—Coldest morning for this season. Minimum temperature, 22.2°. Ice ½ inch thick on ponds and still waters.

1887.

January 22.—A thunderstorm of considerable intensity occurred this morning. The storm came from the southwest and traveled towards the northwest. The temperature before the storm was 47° and did not change much during its passage. First thunder at 6.28 a. m.; loudest at 6.30 a. m.; and last at 7.10 a. m.

February 8.—Rain all night, and this morning was attended by lightning and thunder. It occurred between 6.18 and 6.22 a. m. The temperature at the time was 54°. Rain ended at 12.30 p. m. Maximum velocity of wind 31 miles, west.

February 17.—A thunderstorm passed over the station between 10 and 11.10 p. m. Sharp flashes of lightning and moderately heavy thunder.

March 12.—A large flock of wild geese observed moving south at 9.45 p. m.

April 2.—The first appearance of bluebirds and robins was noticed this morning.

April 8.—A magnificent lunar corona, consisting of four well defined rings, was observed at 9.45 p. m. The inner ring was of a pale green, the second of a bright yellow, the third of a reddish, and the fourth and outer ring of a pale green color. Diameter of outer ring about 5°.

April 23.—The breaking up of the ice in the Straits of Mackinac opens navigation at Chicago.

May 22.—A thunderstorm which exhibits great energy is moving from west to east north of the station. The oppressive air of a few minutes ago is replaced by decidedly colder air.

July 9.—At 2.30 a. m. a thunderstorm was noticed approaching from the southwest, moving southward. There was much thunder and lightning. Thunder first heard at 3.30 a. m.

July 17.—Extremely hot. Many deaths in city resulting from heat. High southwest to west and northwest winds. A brisk thunderstorm passed over the station between 5 and 6.45 a. m. It apparently developed a few miles southwest of the city and moved from southwest to northeast.

August 10.—Thunderstorm after sunset. 11.10 p. m. rolling thunder was heard northwest. The storm moved from west to east and was attended by heavy rain.

August 18.—Between 6 and 7 p. m. a heavy storm passed over the city from west to east. It was attended by much thunder, lightning, and some hail. The hailstones were not large nor numerous. They were opaque, as large as peas, irregular in shape, and flat. The storm probably did not exceed a mile in diameter.

August 31.—The crops in this vicinity have been improved by the recent rains, but are not up to the average, nor is it likely they will be this season.

September 23.—At 6.45 a. m., at the Union Depot, rain was noticed falling when there were no clouds within 10° of the zenith. At 6 p. m. hail was noticed falling with the rain. The hailstones were about the size of peas. They were not numerous.

September 24.—The first frost of the season this morning. Brisk showers during the early morning.

October 12.—The first killing frost of the season occurred this morning. The ground was white, and ice to the thickness of ½ inch formed on water in buckets.

October 23.—The wind blowing a gale of 40 miles. Much damage done to trees, signs, etc.

1888.

January 12.—Rapid and decided changes in pressure and temperature. Barometer fell 0.84 inch in 15 hours. Temperature rose from —4.0° after 7 a. m. to 36.5° at 10 p. m.

January 15.—A severe cold wave accompanied by very high barometer. Height of barometer at 10 p. m., 30.89. Minimum temperature, —14.3°.

January 16.—Barometer (reduced) at 7 a. m., 30.93 inches, the highest observed since opening of station. Continued cold weather in morning, followed during day and evening by rising temperature. Minimum temperature, —16.8°, the coldest since January, 1884.

January 28.—Total eclipse of the moon this day from 2.28 to 8.12 p. m. Clearly visible. A brilliant lunar corona was observed at 6.30 p. m.; the color of the concentric rings being very clearly and distinctly defined. From the inner ring, which was of deep blue, the color faded into almost a pure white at the center of the middle ring. As the outer ring was approached a pinkish tint was observed, deepening to an orange as it neared the center of the outer ring, and finally assuming a deep red hue at the circumference. Diameters: inner ring, about 5°; middle ring, about 8°; outer ring, about 12°. Disappeared at 7 p. m.

February 9.—Coldest day of the season. Minimum temperature, —17.5°.

April 5.—Thunderstorm, with light rain and light southwest winds, passed over station in early morning, moving northwest to southeast. Thunder first heard at 12.15 a. m., and continued during the early morning, with vivid lightning.

April 15.—Thunderstorm in early morning; direction not known; first heard about 2 a. m.; loudest, 5.05 a. m.; last heard at 6.45 a. m. Hail at intervals till 6.45 a. m.; size of hailstones, .02 inch.

April 29.—Temperature fell 46° from 3 p. m. 25th to 7 a. m. 29th.

May 3.—Thunderstorm in early morning; first heard at 12.45 a. m.; loudest at 12.55 a. m., and last heard at 1.10 a. m. Storm moved from west towards east.

May 27.—Heavy thunderstorm in afternoon and evening; loudest at 5.42 p. m. Storm moved from west towards east. Hail from 6.55 to 7 p. m.; size of hailstones, 0.3 inch.

May 28.—Thunderstorm in afternoon; loudest at 2.55 p. m. Storm moved from southwest to northeast. During the storm the barometer rose almost in an instant from 29.59 to 29.73, falling again in a few minutes to 29.62.

June 1.—Thunderstorm. As the wind changed to north the temperature fell rapidly, falling from 68° at 3 p. m. to 48° at 10 p. m.

July 3.—Thunderstorm moving from southwest towards east, and accompanied by excessive rainfall. From 11.22 p. m. to 11.45 p. m. .75 inch of rain fell—at the rate ot 1.90 inch per hour. Thunder first heard at 11.15 p. m., and continued during the night.

July 12.—At 12.20 p. m. the thermometer fell from 86° to 64° in about 5 minutes, while the wind, which had been southwest, shifted to northeast.

July 31.—The warmest day of the season; maximum temperature at 3 p. m., 94°. At

4.55 p. m. a severe thunderstorm arose, accompanied by very heavy rainfall and high north winds. A second thunderstorm, accompanied by vivid lightning, occurred in the morning.

August 2.—A terrific thunderstorm occurred in the late afternoon, accompanied by vivid lightning, excessive rainfall, hail, and high winds. Maximum wind velocity 40 miles, northeast. Thunder loudest at 6.47 p. m. Storm moved from northwest towards southeast. Hail from 6.45 to 6.47 p. m. Size of hail ¼ inch. From 6.27 to 7 p. m. the rainfall was terrific; and it is estimated that 1.50 inch of rain fell in 33 minutes.

September 14.—First frost of the season observed this a. m.

October 2.—Hail from 1.55 to 2 p. m.

October 18.—During the high wind, which occurred about 1 p.m., the barometer suddenly fell from 30.05 to 29.89, rising again to 29.95 in a few minutes. A violent thunderstorm occurred in the evening, accompanied by heavy hail and a magnificent display of lightning. The hailstones varied in size from that of a pea to a walnut, and fell with great rapidity from 6.50 to 7.05 p. m. The lightning flashes were almost continuous from 6.45 to 7.30 p. m., and presented every conceivable form.

November 5.—Thunderstorm in morning and evening.

December 26.—Barometer fell to 29.38 at 3 p. m. High wind continued until after midnight, veering to southwest. The long duration of this gale is almost unprecedented in the history of this station.

1889.

January 1.—Partial eclipse of the sun observed, commencing at 4.21 p. m. The sun disappeared at 5.44 p. m., with but ½ of its surface hidden.

January 9.—The barometer had been falling very rapidly during the night, reaching 28.96 inches at 8 a. m. It continued to fall until 12 m., when it read 28.87, the lowest on record at this station.

January 20.—Heavy snow commenced at 12.45 a. m. and ended at 1.50 p. m. Amount of snowfall, 4.5 inches.

March 30.—Hail, accompanied by thunder and lightning, commenced at 7.20 p. m. Size of hailstones very small.

April 15.—Season of navigation now fully open.

May 8.—Continued warm weather, winds fresh to high south-southwest. Maximum velocity 30, southwest.

May 9.—The exceptionally protracted period of high temperature was terminated to-day by a terrific thunderstorm, accompanied by a severe hailstorm and a magnificent display of lightning. At 5.20 p. m. the temperature suddenly fell from 87° to 72°, and at 5.36 p. m. the first thunder was heard and lightning first observed. The rain fell gradual at first, but at 6 p. m. it fell in torrents for a few minutes, changing then to hail, which fell very rapidly, covering the pavements in some places to the depth of ½ inch. Some of the hailstones were over 1 inch in diameter. The shapes of the stones varied, the larger ones being spherical and the smaller ones oval. The barometer fluctuations in the late evening were quite marked, the barometer suddenly rising .08 inch about 9 p. m. and falling again .10 inch by 11 p. m.

July 18.—In the late evening a fierce thunderstorm occurred, accompanied by incessant lightning, high winds, and the heaviest rainfall ever known in the history of the station., 1.60 inch falling from 11.48, July 18, to 12.50 a. m., July 19. From 11.48 to 11.58 p. m. .80 inch fell, or at the rate of 4.80 inches per hour. Thunder first heard at 9.07 p. m.; loudest at 11.26 p. m., and last at 12.45 a. m. Storm moved from northwest towards southeast.

July 27.—Tremendous thunderstorm in evening, accompanied by lightning and heavy southwest winds. About 7 p. m. the temperature fell suddenly from 82° to 67°, and rain fell in perfect torrents from 7.06 p. m. till 10.40 p. m. A trace of rain also fell from 6.45 to 6.50 p. m. In all, 4.02 inches of rain fell in 3 hours and 36 minutes.

Large hailstones fell in southern and western portions of the city, although none were observed at the station. This rainfall was the heaviest in the history of the station. From 7.25 to 7.38½ p. m. .40 inch fell, and from 7.44 to 7.49 p. m. .80 inch fell. For one or 2 minutes rain fell at the rate of 6 inches an hour. The damage done by the storm was enormous, amounting to over $1,000,000 in this city. Several lives were lost by falling buildings. Summary of storm as follows:

Thunder first heard at 6.40 p. m.; loudest at 9.08 p. m., and last heard at 10.30 p. m. Storm moved from southwest toward northeast. Direction and temperature before storm, southwest, 84°; after, southwest, 65°. Rain from 6.45 to 6.50 p. m., and from 7.06 to 10.40 p. m. Amount, 4.02 inches.

August 3.—Thunderstorm, accompanied by lightning, in evening. Thunder loudest at 11.04 p. m. Storm moved from northwest toward southwest. In the southern portion of the city the storm was quite heavy, where it is estimated that over one inch of rain fell.

August 31.—This month has been remarkable for the absence of rain, but 0.39 inch having fallen.

September 15.—Warmer in early morning, becoming suddenly cooler about 10.30 a. m., and remaining so; the temperature fell from 74° to 61°.

November 21.—A very remarkable day. About 9.15 a. m. a heavy darkness settled over the city, the streets becoming as dark as they ordinarily are at midnight. The darkness was, no doubt, due to the mingling of particles of vapor and the heavy smoke, caused by the excessive use of soft coal, the wind being so light that it was not able to carry off the smoke. The darkness lasted until 11.45 a. m., or about 2 hours, and during that time outside business was practically interrupted. The entire day continued darker than usual.

November 28.—Very severe gale blowing all day. Maximum velocity 37 miles, west. Much damage on Lake Michigan, numerous vessels disabled. One steam barge ashore a short distance above the city. Severe storm will probably practically end navigation for the season on the Great Lakes.

1890.

January 6.—Station visited in early morning by a very unusual winter phenomenon—a thunderstorm accompanied by lightning. Thunder first heard at 12.22 a. m.; loudest at 12.28 a. m., and last at 12.30 a. m. Storm evidently moved from west toward east. Direction and temperature before storm southwest, 56°; after, northwest, 30°.

January 12.—The temperature reached the exceptionally high point of 62.2°. Barometer fell very rapidly, falling from 30.02 at 8 a. m. to 29.29 at 8 p. m., or .73 inch.

January 22.—Temperature below zero for the first time this winter. Minimum, —5.1°.

February 3.—Lightning observed at 6.45 p. m., and thunder heard in several portions of the city.

February 7.—Snow from 9.28 a. m. to 5.30 p. m. Amount of snowfall, 5.8 inches.

March 25.—Winds, high westerly, reaching an extreme velocity of 80 miles at 10.54 a. m.

March 27.—Thunder in evening, accompanied by lightning.

April 3.—Thunderstorm, accompanied by lightning, in early evening.

April 5.—Moon dogs were observed at 9 p. m. The moon at that time was about 15° above the horizon. A bright streak of light extended about 5° on each side of the moon, and at right angles to the horizon. On a line parallel to the horizon were two spots, one on either side of the moon. These spots were small and highly colored, nearly all of the prismatic colors being distinctly visible, the brightest of which were violet and green. The spots lasted about an hour, but the streak of light was still to be seen at midnight, although at that time it was rather indistinct.

April 7.—In late evening a thunderstorm, accompanied by lightning, occurred.

April 8.—Temperature fell from 68° to 45° from noon to 8 p. m. Thunderstorm in early morning. Shortly before 5 a. m. the barometer fell almost suddenly .17 inch, then rose .10 inch, fell .09 inch, then rose .05 inch by 6 a. m. The sudden and severe oscillations caused a succession of small tidal waves on Lake Michigan, at intervals of about 10 minutes, from 5 a. m. to 11 a. m. The water from the lake rushed into the Chicago River and tore several vessels from their moorings. The damage was comparatively slight.

April 18.—Thunderstorm in afternoon and evening, accompanied by lightning and high northeast wind. Thunder first heard 5.5 p. m., loudest at 5.56 p. m., and last at 9.15 p. m. Storm moved from the west towards the east.

April 23.—About 6 p. m. the temperature fell suddenly about 15° (from 70° to 55°) and the wind changed to northeast.

April 30.—At 6 p. m. temperature fell suddenly about 15°, and continued to fall, reaching 48° above at about 8 p. m. Winds high southwest shifting to northeast at 5.40 p. m.

May 3.—Temperature continued to rise until 12.30 p. m., when it fell suddenly about 25° in the next half hour. Winds fresh southwesterly, veering to the northwest at about midnight; thunderstorm occurred in afternoon. Storm moved from the west towards the northeast.

May 9.—Late in afternoon the wind backed to northeast and the temperature suddenly fell 15°. Thunderstorm in evening.

May 12.—Thunderstorm, accompanied by lightning, in morning. Storm moved from northwest toward southeast. Towards evening the wind shifted from south to northeast, and the temperature fell, almost suddenly, from 64° to 48°.

May 22.—Thunderstorm in the evening, a great display of lightning was seen during the entire storm, in the southeast and south. The storm moved from the west towards the east. Winds northerly, shifting to southerly.

May 24.—Thunderstorm in the afternoon, accompanied by vivid lightning. Storm moved from west towards the east. Hail from 1.20 to 1.27 p. m. Hailstones as large as robin's eggs fell. Amount of rainfall, .73. The temperature fell about 13° during the storm, and then rose again to the normal.

June 3.—Thunderstorm, with lightning, in early morning.

June 11.—Thunderstorm, accompanied by vivid lightning of every description, in evening. Storm moved from west toward northeast.

June 18.—Thunderstorm commenced at 1.58 p. m., and was of a very extensive character. For an hour its approach was watched. About the time rain commenced the rain front was estimated to be at least 40 miles long, with much lightning to the south. Its movement was east by south. Thunder loudest at 2.48 p. m. Direction from which storm moved, southwest to northeast. Direction of wind and temperature before, east, 67°; after, east, 64°.

June 27.—Brisk and rather severe thunderstorm occurred, the temperature fell from 86° at 2.45 p. m. to 69° at 4 p. m., and the wind shifted suddenly from south to northeast. After the storm, which was accompanied by zigzag lightning, and moved east across the lake, the temperature rose rapidly, reaching 89° a few minutes after 6 p. m. Direction from which storm moved, northwest toward southeast.

June 29.—Thunderstorm in the afternoon, accompanied by lightning.

July 3.—Thunderstorm in the afternoon. Heavy rain fell after the thunderstorm had ceased; .25 inch falling in 5½ minutes, from 7.03 to 7.08½ p. m.

July 9.—Cooler. High winds; maximum velocity 88, northeast.

July 12.—Thunderstorm in late morning.

July 14.—The temperature reached 90° shortly before 1 p. m., at this time the wind shifted suddenly from southeast to northeast, and increased to a velocity of 36 miles per hour. Within 15 minutes the temperature had fallen from 90° to 68°, and a very severe thunderstorm passed about 2 miles east of the station, moving from north to southeast. The rain area appeared to have a direct easterly motion, and heavy rain could be seen falling a short distance out on Lake Michigan. At 4 p. m. thunder was again heard, and along the horizon there appeared a line of the darkest purple. The rain fell in torrents and the wind reached a velocity of 48 miles per hour. The rainfall was excessive, one inch falling from 5.18 to 5.47 p. m. From 5.31 to 5.34 p. m. .25 inch fell, or at the rate of 7 inches per hour. Direction from which storm moved, northeast towards south.

August 3.—Continued warm weather until nearly 4 p. m., when a thunderstorm arose, and the temperature fell from 95° to 75°, wind shifted from south to northwest and then northeast; becoming fresh.

October 12.—Thunderstorm in afternoon. Storm moved from north towards southeast.

October 13.—Considerable damage done on the lake to shipping by the high wind. A gale blew from the southwest after 8 a. m. Maximum velocity 50 miles per hour, southwest.

October 27.—Killing frost in a. m.

November 8.—Dense fog after 8 p. m. The barometer fell rapidly after 11 a. m. and the wind gradually increased in force, until it reached a velocity of 44 miles, southeast.

December 4.—Snow commenced at 5.30 p. m. and continued. Amount of fall to midnight, 3.5 inches.

1891.

January 1.—Shortly before 1 p. m. the wind, which had been southerly, backed to northeast, and the temperature commenced to fall rapidly.

February 19.—Snow commenced at 5.45 p. m., changing to hail at 6.30 p. m., and again to rain at 8.50 p. m. The fall of hail was very heavy, at least 2 inches having fallen. The storm was accompanied by a high wind and frequent and decided barometric oscillations, the alternate rises and falls in several cases amounting to 0.10 inch in a very short space of time.

February 24.—Thunderstorm in late afternoon and early evening, accompanied by lightning and high wind. Storm moved from southwest towards northeast. Maximum velocity 60 miles, southwest.

March 30.—Thunderstorm occurred just after noon. Storm moved from west towards east.

April 17.—Heavy thunderstorm, with lightning, occurred in evening. Storm moved from west towards east.

April 21.—Heavy thunderstorm, with lightning, in afternoon and evening. Storm moved from west towards east.

May 15.—Warmer until 4.45 p. m., when wind shifted from west to north and became high, and temperature commenced to fall rapidly; from 4.45 to 6 p. m. it fell from 77° to 49°.

May 20.—Thunder and lightning in early evening. Storm moved from west towards east.

May 21.—Thunderstorm in afternoon. Temperature stationary until afternoon, when wind shifted from southwest to northwest, with a fall in temperature of about 21°.

June 1.—Thunderstorm, with lightning, in late afternoon. Heavy rain, with hail, in southern portion of city. Storm moved from southeast towards northwest. Second thunderstorm, with vivid lightning, in late evening. Storm moved from north towards east.

June 3.—Wind shifted from southwest to northeast, increasing in force, and temperature fell suddenly from 83° to 62°. Thunderstorm commenced shortly after. In the interval between the rain the temperature rose slightly and the wind shifted to southeast, but at 10.30 p. m. the wind backed to northeast and the temperature again fell suddenly from 63° to 48°. Thunderstorm moved from northwest towards east.

June 16.—Little warmer during the day until 5 p. m., when, with northeast wind, the temperature fell about 15°—to 72°. Thunder and lightning shortly after midnight. Thunderstorm in the evening, with lightning. Storm moved from west towards east.

July 17.—Little change in temperature until late afternoon, when wind shifted to west and northwest, and temperature fell about 12°.

August 9.—Maximum temperature, 96.1°. 4 p. m. wind shifted to northeast, and temperature fell suddenly from 96° to 74°. Thunderstorm, accompanied by lightning, followed shortly after. Storm moved from northwest towards east. Direction of wind and temperature before storm, southwest, 92°; after, west, 74°.

August 19.—Thunderstorm, with lightning, in late afternoon. Storm moved from southwest towards northeast. A peculiarity of the storm was, that it was decidedly local, no rain falling 4 miles from this office.

September 14.—Thunderstorm in evening, with lightning. Storm moved from northwest toward southeast.

September 20.—Cloudless and very warm. The long duration of the present warm period is unprecedented for September, the mean temperature for the past 5 days being above 75°. Brisk to high southwest winds.

September 24.—Continued warm and cloudless. Warmest day of month. Maximum temperature 90.8°, being only the sixth day in September for 21 years in which the maximum temperature exceeded 90°.

September 27.—Warmer and generally cloudless. Southerly winds.

September 28.—Temperature a little lower during the day until about 7.30 p. m., when wind shifted to northwest, and temperature fell rapidly from 74° to 56°. A light thunderstorm, with rain and lightning, occurred about the same time. Storm moved from northwest to southeast.

September 30.—First light frost of the season this morning.